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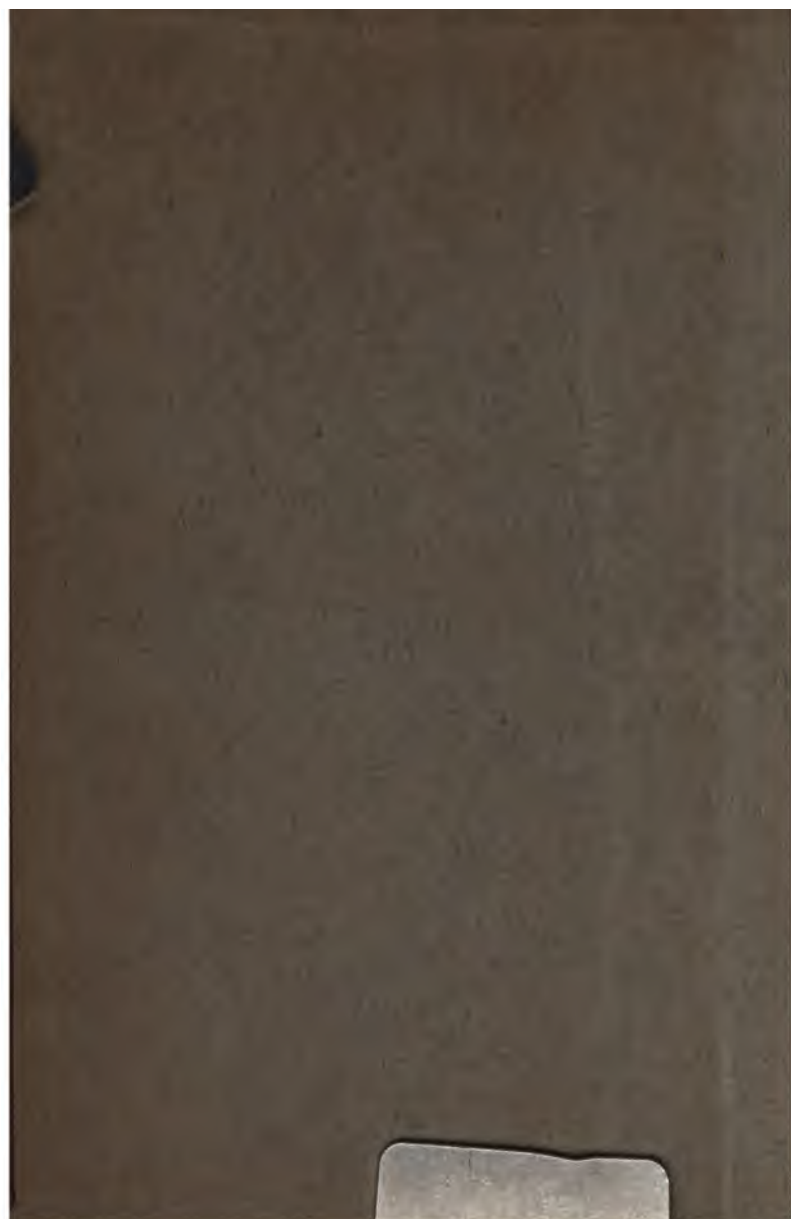
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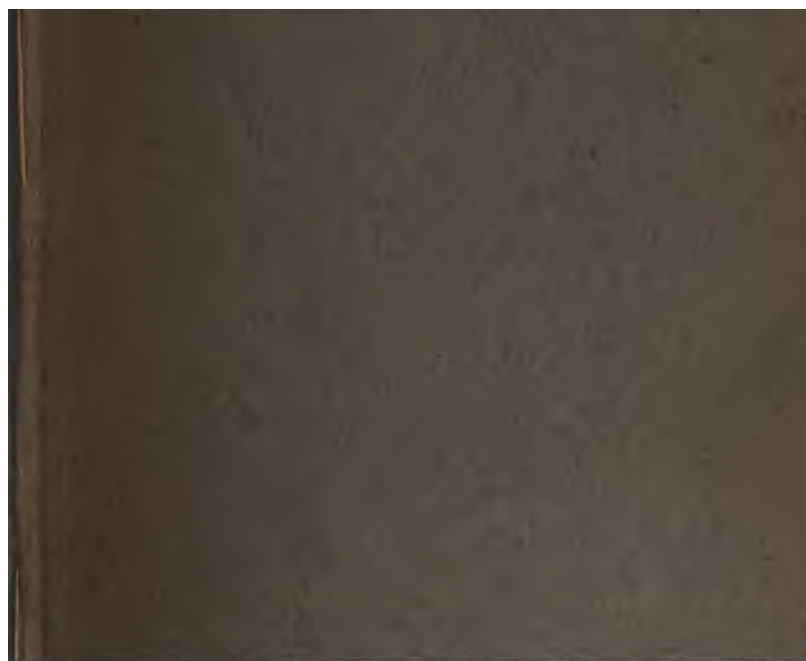
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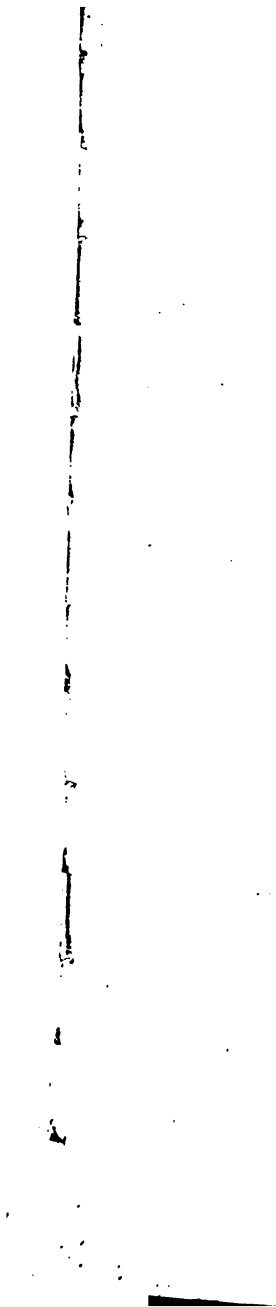
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RESEARCHES
ON THE ACTION OF
THE BLAST-FURNACE.

Karl
BY CHARLES SCHINZ.

TRANSLATED FROM THE GERMAN, WITH THE SPECIAL PERMISSION OF
THE AUTHOR, BY

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WITH AN APPENDIX WRITTEN BY THE AUTHOR EXPRESSLY FOR THE
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TRANSLATORS' PREFACE.

IN laying before the public an English edition of M. Schinz's 'Dokumente betreffend den Hohofen zur Darstellung von Roheisen' the translators feel that but few words of introduction are necessary. The work is one which possesses a special value from the extensive collection of experimental data which it contains, and it has already been extensively quoted in the leading English professional journals. In preparing the present edition, the translators have had the benefit of the direct co-operation of M. Schinz, who has made many additions to the original text, and who has moreover supplemented the work by an Appendix containing an account of his most recent investigations.

AUTHOR'S PREFACE.

ARDENTLY devoted to the art of measuring heat and applying it rationally in the various branches of industry requiring its aid, I naturally made the manufacture of iron an object of my studies.

Of course the natural laws which govern the production as well as the application of heat are always the same, whatever may be the speciality to which they have to be applied; each speciality, however, offers its own and peculiar conditions, which have to be known in order that success may be attained.

To this end I obtained the best works treating of the metallurgy of iron—works which were so designated by ~~profession~~

men. I must confess, however, that I was not at all satisfied with what I found, and as at the period of which I am speaking the new form of the blast-furnace, by Major-General Rachtke, became known, I was induced—as the undoubted success of this furnace in Russia was sufficient to terminate at once the dispute amongst metallurgists as to the form of the blast-furnace—to express my opinion of this furnace, and to inquire into the want of scientific knowledge in that branch of science.

The gauntlet thus thrown down was eagerly taken up by several opponents; my opinion was declared to be without any foundation; and it was affirmed that this could easily be explained by the circumstance that a man not belonging to the profession could not be acquainted with the whole literature of the metallurgy of iron. Further, to correct my errors a great many books were recommended to me.

An article, published in No. 45 of the Austrian Mining Journal ('Oesterreichische Zeitschrift für Berg- und Hüttenwesen') of the year 1863, without the name of the writer, but dated Leoben, 25th of October, 1863, accuses me of having written with an astonishing self-consciousness, with a proud self-esteem, and with a disregard of the opinions and studies of well-known authorities. Another anonymous opponent appeared in Nos. 1 and 2 of the journal 'Berggeist,' 1864.

These replies were not calculated to improve my opinion of the scientific researches of the German metallurgists. Everybody may judge for himself, by the following extracts from the books recommended, whether I am right in this respect.

M. Carl von Mayrhofer's 'Studien des Hohöfeners' was recommended to me as the best book in metallurgical literature, and I shall now give a few sentences from that book.

Page 136. "Cold iron forms also part of the flux for the charges, because it possesses the property of separating a portion of the silicium from the liquid iron."

"The oxygen has to act upon the fuel with a certain—and, if possible, uniform—intensity, in order to produce a rapid combustion of the fuel, and to prevent its partial destruction by the gusts of blast."

"Calculating from the consumption of the materials the temperature which is required for the production of spiegeleisen, we find it to be between the limits of 1826° and 1889° , that is to say, it is on the average 1850° ."

The absurdity of these sentences being but too evident, no further remarks are required.

Amongst the literature recommended to me I found a paper by M. Tunner, in which the author says:—"In the reduction and carburization of very fusible ores, the one half of the carbon consumed serves for the fusion and the other half for the reduction, whilst in the case of less fusible ores $\frac{3}{4}$ of the consumed carbon is required for the fusion and $\frac{1}{4}$ for the reduction and carburization." The anonymous writer in the '*Berggeist*' makes the same mistake; after giving different analyses of the gases from blast-furnaces, he calculates the consumption of the carbon to be as follows:—

For the production of heat =	78.48	61.78	64.68	66.06	77.14	per cent.
„ reduction .. =	21.52	38.22	35.32	33.94	22.86	„

How is it possible that professors of a school of mines and practical metallurgists do not know that all the carbon in the blast-furnace is transformed into carbonic oxide, and thus produces heat, whilst the gas produced combines chemically with the oxygen of the oxide of iron of the charges? But my opponent in the '*Berggeist*' is not yet satisfied with this statement of the action of the blast-furnace, which he proposes without even caring for my disapprobation; he calculates the quantity of oxygen which enters the furnace by means of the section of the tuyere holes and the pressure of the blast, and wants to

introduce into the furnace as much air as possible, in order to produce more carbonic acid; it is thus he contradicts my objections made to M. Tunner. The latter had expressed his opinion on Rachette's furnace at the International Exhibition of 1862 in the words, "The advantages of this furnace consist chiefly in the better distribution of the blast." This sentence, which had in itself no sense, but could be explained in future in any manner according to circumstances, I termed the speech of an oracle. This explanation is now given:—"Better distribution by means of a larger production of carbonic acid"!

My anonymous opponent of Leoben speaks finally of the large zones of preparation as demanded by me, and regrets that the advantages of the Rachette furnace may possibly not be proved by experiments which are either based upon such erroneous opinions or which cause useless expense.

" Dans un chemin montant, sablonneux, malaisé,
Et de tous les côtés au soleil exposé,
Six forts chevaux tiraient un coche.
Femmes, moines, vieillards, tout était descendu :
L'attelage suait, soufflait, était rendu.
Une mouche survient, et des chevaux s'approche,
Prétend les animer par son bourdonnement,
Pique l'un, pique l'autre, et pense à tout moment,
Qu'elle fait aller la machine.
S'assied sur le timon, sur le nez du cocher.
Aussitôt que le char chemine,
Et qu'elle voit les gens marcher,
Elle s'en attribue uniquement la gloire.

* * * *

Après bien du travail, le coche arrive au haut.
Respirons maintenant ! dit la mouche aussitôt :
J'ai tant fait que nos gens sont enfin dans la plaine.
Ça, messieurs les chevaux, payez-moi de ma peine."

Even if the works on the blast-furnace can show some better, however—and some of these works contain most valuable information—it must nevertheless be admitted that this industry has not kept pace with the advance of science.

true statement either of the quantities or intensities of the calorific, mechanical, or chemical actions which go on in the furnace is not to be found, although it is the only means by which facts can be made useful and systematically arranged.

When I tried six years ago to establish such a statement out of the elements given by the manuals on metallurgy, I only found the solution of the problem possible by making arbitrary suppositions which had no foundation whatever. I then saw, however, the possibility of establishing a system approaching the truth very nearly, if the numerical values of many factors acting in the blast-furnace could be determined by extensive experiments. I, therefore, carried on this work with great perseverance and at considerable expense during six years, and my expectation that conscientious researches would give the desired results has been entirely fulfilled.

Although it may be desirable that some of my results should be more exact, they, nevertheless, enable the connection between the factors to be seen and their respective positions to be ascertained. The experiments made are divided into the five following categories :—

1. Analyses of the process of combustion, surface of contact, and influence of the temperature.
2. Specific heat, latent heat, and heat of combination of the bodies used in the blast-furnace.
3. Transmission of the heat to the air surrounding the walls of the furnace, this causing the temperature in the furnace to be much lower than is generally supposed.
4. The chemical process of the reduction of the oxides of iron by the gases of the furnace. These investigations have not only been of use in improving the

knowledge of the processes which go on in the blast-furnace, but they have also been the means of proposing an important improvement of this process.

5. Finally, the investigations on the resistance of the column of fusion, which, although not giving values of great exactness, are, nevertheless, of the greatest importance with respect to the form of the blast-furnace.

The ideal of every branch of industry is not only the most economical manufacture of its products, but also their perfection. I hope to have successfully demonstrated that the rational working of the blast-furnace can fulfil these two conditions; may the following work, therefore, contribute to this end.

C. SCHINZ.

STRASBOURG, *May*, 1868.

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THE BLAST-FURNACE.

INTRODUCTION.

EXACT knowledge is necessarily composed of three things: the facts of which it is constituted, the ideas by which these facts are recalled, and the words by which they are expressed. The word calls forth the idea, the idea represents the fact; these are three impressions of the same seal.

This ingenious definition of exact science, by Lavoisier, also forms a criterion by the aid of which it can be ascertained whether, and how far, any special knowledge can lay claim to a scientific character. If we apply these principles to the study which comprehends metallurgical knowledge, and especially the blast-furnace, we find that it cannot lay much claim to the name of a science. Even the more scientific researches, as, for instance, the determination of the constituents of the pig-iron, of the slags, and of the ores, in no way form a system which comprehends all phenomena, and shows their dependence on each other. Moreover, investigations of this kind made without regard to the general conditions of the question, have given rise to prejudices which have opposed real progress.

If, for example, the bed of fusion is arranged with a view of producing a slag which shall be a bi- or a tri-silicate, the principal end is evidently lost sight of; for the production of the pig-iron depends more upon the greater or smaller quantity of the slags produced than upon their quality. The proportion between the quantity of the materials composing the slags and of the amount of the oxide of iron in the shaft of the furnace determines the time during which a given quantity of oxide of iron is exposed to the reducing gas; a decrease of the quantity of the slag increases, therefore the quantity of oxide of iron

which is exposed to the gas in a unit of time, whilst an increase of the amount of slags extends the time during which the oxide of iron and the reducing gas remain in contact, and this is the important point.

If, for example, it could be ascertained that ten hours of contact with reducing gases of a certain quantity and quality are necessary for the complete reduction of 100 kilogrammes (220 lbs.) = 0.036 cubic mètre (1.27 cubic foot) of oxide of iron to metallic iron, the calculation for composing the charge would thus be facilitated, and the quantity of the slag-forming materials, which would allow the 100 kilogrammes of oxide of iron to remain during 10 hours under the influence of the reducing gases, could be determined.

The time, the volume of the oxide of iron, that of the materials composing the slag, that of the coals or coke, and the quality and the quantity of the gas in proportion to the time, have in this case numerical values which bear certain proportions to each other, and which combined must lead to the result, that the correct time is allowed for the oxide of iron to be completely reduced to metallic iron.

Besides the six factors above mentioned, there are many others which contribute in a similar manner to the final result, and which have all numerical values which it is important to know, if the whole has to be combined into a harmonious system, and if the knowledge of the action of the blast-furnace is to gain the character of an exact science.

That is the problem which had to be solved, and which forms the subject of the following researches.

Familiar by study and long practice with the applications of heat, I had observed, from the beginning, in studying siderurgical manuals, that in that branch of industry, as well as in all others where high temperatures are employed, no sufficient difference is made between quantity and intensity of heat, and that also one of the principal factors of this subject is completely neglected, namely, the transmission of heat through the walls of the furnaces.

These two *des*

plain how it is pos-

sible that metallurgy has not followed the progress of science, and why perhaps many experiments made privately for forming a system have not been published.

The general opinion amongst metallurgists that the temperature within the furnace walls ought to be as high as possible, originates from the introduction of the hot blast, by means of which it has been rendered possible to save fuel, and at the same time to produce much larger quantities of pig-iron. And although the quality of this pig-iron has been found to be inferior, the connection between these two results could not be explained, because the fundamental suppositions were wrong. It was supposed that the pig-iron and slags must have very high melting points, because it was not known that the transmission through the walls of the furnace absorbs a considerable quantity of heat and diminishes the temperature within the furnace; it was unnoticed that the material to be melted while passing through the shaft of the furnace is surrounded by hot gases, and that it will be liquefied by the least surplus of heat. Of course this increased temperature and simultaneous augmentation of heat, produced by the preliminary heating of the blast, causes a quicker liquefaction of the lower layers of the charge; but the other layers of the charge will at the same time descend much more quickly, and the oxide of iron of the ores thus remains a less time in contact with the gas, and attains, before the reduction is completed, a temperature at which the slags begin to run and dissolve the still unreduced oxide. The ferruginous and thick slag surrounding the pieces of coke or coal and being thus in intimate contact with solid carbon, the ferrous oxide which it contains is reduced, and under the influence of the high temperature the silica, earth, phosphorus, &c., &c., are also brought to a metallic state, and combined with the iron. Of course this direct reduction by means of solid carbon produces also carbonic oxide, and for every unit of weight of carbon thus transformed an absorption of heat to the extent of 2400 *calories** (= 9526 British thermal units). The quantity of heat contained in the hot blast replaces the heat thus absorbed, and

* A *calorie* = 3.96832 British thermal units.

this is simply the reason why a larger quantity of pig-iron is produced without an increase in the consumption of fuel.

This reduction of the iron by means of solid carbon, however, also takes place without hot blast, when the ores contain silicate of iron, or when refinery slags, which are not attacked by the gas, are added to the charge. Ebelmen observed and proved this fact as long ago as 1838; he always found in the gas passing through the throat of the furnace an excess of carbon which could not be burnt by combination with the oxygen of the blast. But this important fact has been passed unnoticed by metallurgists, and thus no such results as might have been expected have been deduced from it.

The starting-point of a scientific system of blast-furnace working, in which all the factors must concur, is therefore the complete reduction of the ores before they arrive at that region at which the temperature is sufficient to liquefy the materials composing the slags.

But what is that temperature, and in what section of the shaft of the furnace does it manifest itself?

Not only the first question, but also many others upon which the solution of the second depends, demand an instrument and a mode of experimenting which enable high temperatures to be measured with exactness. That was the first and at the same time the most difficult problem to be solved; and I commence these papers, therefore, with a description of the thermo-electric pyrometer.

Of course, in order to proceed in a regularly progressive manner, the phenomena of combustion must be next examined, and the numerical values of all factors connected with that combustion must be determined as nearly as possible.

The disposal of the heat produced demanded next the determination of the values at high temperatures of the specific heats of all the materials introduced into the blast-furnace, and also of their latent heats and of the heats of combination, as well as the volume of the materials and the mechanical resistance of the column of fusion to the current of ascending gases.

The transmission of heat through the walls of the furnace, which, it is true, cannot be determined *a priori*, is, however,

a factor of such an importance, that it has to receive special consideration, and its influence had to be ascertained as exactly as possible.

The laws which govern the reduction of ores by means of reducing gases, the time, quantity and quality of the gases, physical condition of the ores and temperature have been the subject of long and laborious study, which however has led me to the most important applications.

By means of the values successively obtained, I have been enabled to consider the relations between these various factors, and especially to determine the volumes of the different zones, which I have named : zone of gasification, zone of fusion, zone of reduction, and zone of preparation. Of course the volume of the zone of reduction is the most important ; but as it depends upon the volumes of the other zones, they all demand our attention.

The times in which the ores pass through the different zones are determined from the cubic contents of each zone. The quantity of iron contained in the charge, the carburization of the iron, the form of the blast-furnace, and other analogous matters affecting the progress of the process and its final result, are next taken into consideration.

The deductions which are to be drawn from these definitions, and comparisons made with the actual course of working, show that the quantity and intensity of heat produced by the carbon are greater than required for the fusion of the iron and the slag ; and consequently that the volume of the zone of fusion has been uselessly enlarged to the detriment of the zone of reduction, and therefore a loss of temperature is at least no loss for the blast-furnace, if the production of the pig-iron has not to be increased to the detriment of its quality. On the contrary, the study of the laws of reduction has proved that with an equal volume the effect of the zone of reduction is considerably increased, if the gases are rich in carbonic oxide.

I have founded upon this fact a new system, which attains the desired aim by partially eliminating the nitrogen in the products of combustion. The description and application of that system to the blast-furnace forms the conclusion of the following work.

CHAPTER I.

PYROMETER.

It is usual in speaking of pyrometrical apparatus to enumerate and to depreciate all varieties previously known, in order that the result may necessarily be arrived at that the new apparatus which is to be proposed surpasses all others. I exempt the reader from such a statement, for it is known that none of the proposed pyrometers, with the exception of the air-pyrometer, can be trusted, nor can their indications be reduced to degrees of the ordinary thermometer. It is also known that the air-pyrometer is almost useless for daily observations of temperature, on account of its difficult management.

The principle of thermo-electricity, already proposed by Becquerel, senior, in 1835, affords therefore the only means of making pyrometrical observations which satisfy the requirements of industry. The thermo-electric pyrometer, constructed and described by Pouillet, however, did not appear to me exact enough for the purpose; and I was very glad when, in 1863, Becquerel, junior, revived the subject, and especially when he substituted the elements platinum and palladium for the elements platinum and iron, for the latter oxidizes easily at high temperatures. But when I repeated the experiments described by Becquerel, I was not only astonished, but also sorry to find that they produced results very different from those given by him.

The elements platinum-palladium gave useful results so long as the temperature was below that of the melting-point of antimony, but then the current suddenly reversed. It was also impossible for me to obtain, with the apparatus for measuring the intensity of the currents, as used by Becquerel, any comparable results. Becquerel used Weber's galvanometer, which, as is known, consists of a magnet mounted with a mirror, so that the latter follows the deviation of the magnetic needle. A horizontal scale, provided at its centre with a telescope with crossed threads, is fixed at a distance of one or two mètres, and the reflec-

tion of this scale in the mirror, as observed through the telescope, indicates with exactness the deviation of the magnetic needle. But I have found that the magnetic needle, if fixed at a given moment upon 0, that is to say, upon the crossing points of the threads of the telescope, is caused to deviate after a short time by the variable current of the earth; and that this is especially the case in the morning between ten and eleven o'clock, and in the evening between four and five o'clock. I, on one occasion, observed between these hours a deviation of $1\frac{1}{4}^{\circ}$, in fifteen minutes. Becquerel's instructions to reduce the deviation of the magnetic needle to 4° by means of bobbins introduced into the current, appeared to me still more incomprehensible, because the resistance of a bobbin varies with the force of the current, and it is therefore a pure impossibility to measure in this manner the intensity of the current with any exactness. I then substituted for the bobbins the rheostat of Wheatstone; but that did not fulfil the desired end on account of the influence of the earth-current of which I have already spoken. I was therefore obliged to return to the elements platinum and iron, and to construct an apparatus for the measurement of the current, which avoids the difficulties above named.

I have thus been successful in constructing the great torsion galvanometer, represented in Fig. 1, Plate I. In this figure A A is a hexagonal case of 1.1 mètre in height, and of which the six sides are glazed. This case is provided with adjusting screws *a, a, a*; so that the instrument can be placed in an exactly horizontal position. Upon the centre of the top of the case is fixed the brass tube *b*, in which moves a second tube, which carries the bevel pinion *c*, and at the top the grooved pulley *d*. To the thin silver wire *f f*, which passes over this pulley through the vertical tubes into the case, is fastened the astatic needle *e e*, which is 0.03 mètre in length. The casing of the galvanometer, which is made of thick copper, and upon which is wound up the coil of wire, is shown in elevation with the astatic needles in Fig. 2, while Fig. 3 is a plan, and Fig. 4 is a transverse section at right angles to the axis. In order to use this galvanometer, the astatic needles must always be exactly in the

direction of the magnetic meridian, and a compass g is therefore fixed at the top of the case AA , Fig. 1, to enable the instrument to be correctly placed. The astatic needles must, when no current is passing, assume exactly the position indicated in Fig. 3, and the position of the pulley d , which with its bracket swings round the tube carrying the pinion cc , is therefore only fixed after the exact position of the needles has been obtained. Another bevel wheel ii , which is in contact with the pinion cc , is fastened to the same spindle as the index hh , Fig. 1. If therefore the latter be turned round upon the divided circle kkk , motion is communicated to the tube carrying the pinion cc , and with it to the pulley d , and consequently also to the wire ff and the astatic needles ee .

If an electro current is now allowed to pass through the conducting wires ll , and through the coils of wire upon the frame, Figs. 2 and 4, the needles ee will deviate from the direction of the magnetic meridian, and of course this deviation will increase with the increased intensity of the current. This intensity of the current is measured by turning the index hh upon the circular scale kkk , until the needles again exactly occupy the position shown by Fig. 3, that is to say, until they are again in the meridian. The circular scale kkk is divided into 360° , and the position of the index thus shows the angle of torsion through which the silver wire has to pass, in order to overcome the intensity of the current which deviated the needle.

This force may become greater or smaller, if the astatic state of the needles changes, and means must therefore be found to ascertain that state. The apparatus represented in Figs. 5 and 6 serves for that purpose. In these views, of which Fig. 5 is a vertical section and Fig. 6 a plan, ff are thirteen thermo-electric pairs, consisting of zinc and nickel wires; and the joints of these thirteen pairs immerse alternately into the reservoirs B and B' , of which the latter is filled with water, that has each time exactly the same temperature, for example $30^\circ C$. The reservoir B , however, consists of three parts, which are put one within the other, and of which the middle one is filled with

paraffin; the second, *a*, is filled with steam from the boiler *k*, the condensed water escaping through the pipe *b*, whilst the outer case *a'* only serves to prevent as long as possible the condensation of the steam in *a*.

After steam has been in *a* for some time, and the temperature of the paraffin has become 100°C ., the water in *B'* is heated to a certain temperature, and the thermo-electric wires *ff* are thus subjected to two constant temperatures and produce a constant current. This current, conducted to the galvanometer, indicates the number of degrees through which the index *h* has to pass, in order to bring back the needle *ee* into the direction of the meridian.

If, for example, the first experiment after the completion of the galvanometer has given for the elements zinc-nickel a torsion of 905° , and next, after a short time, only 897° , it shows that the needles have lost of their astaticity in the proportion of $\frac{905}{897} = 1.008918$. As long as the needles remain, therefore, in that state, the indicated degrees of torsion must be corrected by multiplication in the above proportion.

The astatic state of the needles changes very easily and rapidly, if the needles are allowed to drop or if they come in contact with each other, or also if they are touched with iron; all such accidents have therefore to be prevented. But even if the needles remain suspended, their state is liable to a gradual change, for that needle which is in the magnetic meridian becomes stronger, and the other one pointing in the opposite direction, weaker. The best mode of preventing this change in the astatic state, consists in lowering the upper needle so far after each operation that it touches the frame of the galvanometer, and then turning the needles until they are at right angles to the magnetic meridian, as in Fig. 1. I have by this means been successful in maintaining the needles in a perfectly astatic state during a period of five months; it is, however, advisable and safer to verify them from time to time.

Another cause of variation in the number of degrees indicated by a given current is the increase or decrease of the conductivity

of the wires forming the conductors and coils, caused by changes of temperature. The correction which is thus required for copper wires is obtained by multiplying the number of degrees of torsion by $1 + \alpha t$; in which quantity t = the temperature of the surrounding air, expressed according to the centigrade scale, and $\alpha = 0.004097$. The following Table gives the logarithms of the coefficients of correction for different temperatures according to the centigrade scale.

COEFFICIENTS OF CORRECTION FOR THE CONDUCTIVE RESISTANCE OF
COPPER WIRES.

Normal Temperature = 13.5°C . ; $\alpha = 0.004097$.					
Temp. of the Air.	Log. $1 + \alpha t$.	Temp. of the Air.	Log. $1 + \alpha t$.	Temp. of the Air.	Log. $1 + \alpha t$.
0	0.97529-1	12	0.99732-1	24	0.01829
0.5	0.97623-1	12.5	0.99822-1	24.5	0.01914
1	0.97717-1	13	0.99911-1	25	0.01999
1.5	0.97811-1	13.5	0.00000	25.5	0.02084
2	0.97904-1	14	0.00089	26	0.02169
2.5	0.97997-1	14.5	0.00178	26.5	0.02254
3	0.98090-1	15	0.00266	27	0.02338
3.5	0.98183-1	15.5	0.00354	27.5	0.02422
4	0.98276-1	16	0.00443	28	0.02506
4.5	0.98368-1	16.5	0.00531	28.5	0.02590
5	0.98461-1	17	0.00618	29	0.02674
5.5	0.98553-1	17.5	0.00706	29.5	0.02757
6	0.98645-1	18	0.00793	30	0.02840
6.5	0.98736-1	18.5	0.00881	30.5	0.02924
7	0.98828-1	19	0.00968	31	0.03007
7.5	0.98919-1	19.5	0.01055	31.5	0.03090
8	0.99010-1	20	0.01141	32	0.03173
8.5	0.99101-1	20.5	0.01228	32.5	0.03256
9	0.99192-1	21	0.01314	33	0.03338
9.5	0.99282-1	21.5	0.01401	33.5	0.03420
10	0.99373-1	22	0.01487	34	0.03502
10.5	0.99463-1	22.5	0.01573	34.5	0.03584
11	0.99553-1	23	0.01658	35	0.03666
11.5	0.99643-1	23.5	0.01744		

The intensity of a thermo-electric current is determined, as is well known, by the difference of temperature between the alternate points of contact of the elements. Now in our obser-

vations, one of these temperatures is unknown, but the other one must and can be measured. Thus one end of the element *xx*, Fig. 1, is exposed to a heat of which the intensity is to be determined, whilst the other end is carried through a reservoir W, filled with water, the temperature of which is measured by means of a thermometer.

Unfortunately the intensities of the currents derived from a thermo-electric element are not proportional to the differences of temperature by which they are produced, and it was therefore necessary, to begin with, to prepare a Table by comparing the intensities of the currents of the thermo-electric pyrometer with the temperature shown by an air-pyrometer; the results recorded in this Table thus showing the intensity of the thermo-electric current corresponding to each degree of temperature. A full description of such experiments has already been given in Dingler's 'Polytechnical Journal,' vol. clxxvii, p. 85, and by M. Fièvet in the 'Revue universelle des Mines et de la Métallurgie' of F. de Cuyper of 1866, and it is therefore useless to repeat it here.

It must be stated with respect to the thermo-electric elements, platinum and iron, that the length and diameter of the wires, as well as the quality of these metals, must always be the same, if the currents produced by them are to be identical at equal differences of temperatures. But oxidation changes the iron easily, especially at high temperatures, and it is therefore advisable to cut for each instrument a dozen iron wires of the same coil, so that they may be renewed without any considerable inexactness in the measurements being apprehended.

Even in a clay pipe filled with silicious sand, iron oxidizes by forming at 800° C. silicate of iron; this oxidation is, however, less to be apprehended if the wires in the clay pipe are surrounded with powdered quicklime.

Another source of error is that the conducting power of the wires composing the elements is much decreased after they are strongly heated for a certain portion of their length; and in order to obtain, therefore, comparable results, it is necessary that the wires should be always introduced the same distance

CHAPTER II.

THE PROCESS OF COMBUSTION.

COMBUSTION may be defined as the chemical combination of the oxygen of the air with the carbon and hydrogen contained in the fuel. The products of this combination, however, are not always the same, but vary under different circumstances, which have to be taken into consideration. The quantity and intensity of the heat produced by this process is also dependent upon circumstances.

The circumstances which modify the products of combustion are as follows :

- a. The extent of the area of contact which the fuel offers to the air or oxygen during the unit of time ;
- b. The temperature of the fire ;
- c. The purity and dryness of the air which serves for the combustion ;
- d. The greater or less pressure under which the combustion takes place.

The quantity of heat produced is :

- a. 8000 calories or centigrade units of heat per kilogramme of carbon if only carbonic acid is formed ;
- b. 2400 calories when the same quantity of carbon is converted into carbonic oxide.

At a sufficient temperature the free hydrogen in the fuel always produces water, developing at the same time 34,000 calories of heat per unit of weight ; if the temperature, however, is insufficient, hydro-carbons are formed.

The intensity of the heat depends upon :

- a. The mixture of the products of combustion with other incombustible matters, as for example, with nitrogen or with steam, which diminishes the effect ;

- b. The effective quantity of the heat produced ;
- c. The pressure under which the products are formed.

All these conditions must now be examined more closely.

CHAPTER III.

AREA OF CONTACT.

A CHEMICAL action can only take place between two bodies, however great their affinity, if they are in intimate contact with each other; and the rapidity of this action will be so much greater, the more numerous the points of contact are. The smaller, therefore, the pieces of any fuel are, the greater is the number of the points of contact which the same mass of fuel offers to the oxygen reacting upon it. A confirmation of this is found in the method well known in America of burning fuel in the form of dust. That method of firing consists in blowing the fuel through hot air into the furnace, thus producing a very intense combustion. But I do not believe that this method will ever be generally used, because it will never be possible to combine the fuel and air in proportions which are even approximately correct, and because it is less expensive and more rational to transform the fuel into combustible gases, which are then consumed with the correct quantity of air.

In order to determine in a more precise manner the influence of the surface of contact upon the process of combustion, I have made the following series of experiments :

I at first had the fuel made in pieces of almost uniform size of 35, 30, and 20 millimètres diameter; and an approximate value of the surface of contact of these pieces may be obtained by considering them as spheres.

If l is supposed to be the side of the cubic mètre, n^3 the number of pieces which one cubic mètre contains, and d the diameter of the pieces, we get :

$$n^3 = \left(\frac{l}{d}\right)^3; \text{ and therefore}$$

if $d = 35^{\text{mm}}$ one cubic mètre contains $\left(\frac{1000}{35}\right)^3 = 23322$ pieces

if $d = 30^{\text{mm}}$ „ „ $\left(\frac{1000}{30}\right)^3 = 37038$ „

if $d = 20^{\text{mm}}$ „ „ $\left(\frac{1000}{20}\right)^3 = 125000$ „

The surface of each of these spherical pieces is :

$$0.035^3 \pi = 0.0038485 \text{ square mètre}$$

$$0.030^3 \pi = 0.0028274 \quad \text{„} \quad \text{„}$$

$$0.020^3 \pi = 0.0012567 \quad \text{„} \quad \text{„}$$

If the transverse section of the hearth, and the height of the layer of the fuel above the grate are known, it is very easy to calculate the volume, and consequently also the surface of the pieces.

In order to ascertain the volume and velocity of the entering air, we have only to calculate the area of the spaces between the various pieces of the fuel and the volume, according to the hourly consumption, and the analysis of the products of combustion. The space between the pieces of the fuel is always the same for the sectional area, whether the pieces are large or small, for it is :

$$1 - \left(n^2 \frac{d^3 \pi}{4}\right) = S.$$

For example, the number of spheres of 30 millimètres diameter for a surface of one square mètre is :

$$n^3 = \left(\frac{l}{d}\right)^3 = 1111$$

and the free space between them is, therefore,

$$1 - \left(1111 \cdot \frac{0.03^3 \pi}{4}\right) = 0.2146 \text{ square mètre,*}$$

* These calculations are made on the supposition that the globules lie together, so that lines joining their centres form squares, in which case the "free space" amounts, for each globule, to the difference between the area

and for spheres of 20 millimètres diameter

$$1 - \left(2500 \frac{0.02^3 \cdot \pi}{4} \right) = 0.2146 \text{ square mètre.}$$

The chemical analysis of the products of combustion shows the proportion of the different gases, but not their absolute volume; but if the hourly consumption of carbon be known, the absolute volume of the products of combustion can be calculated.

If, for example, an hourly consumption of 0.8 kil. of coke contains 0.692 kil. carbon, or a volume of 0.6451 cubic mètre, the analysis of the gases gives

18.155	volumes	per cent. of C O ²
1.431	„	„ C O

which contain :

the first	9.0775	volumes of carbon
the second	0.7155	„ „
together	9.7930	„ „

We get from the proportion 9.7930 to 0.6451 :

	Vol.	Cubic mètres.		Cubic mètres.	
N	76.196	= 3.987	.. ..	= 3.987	N
O	0.620	= 0.040842	.. ..	= 0.040842	O
C O ²	18.155	= 1.195900	.. ..	= 1.195900	O
C O	1.431	= 0.094265	.. ..	= 0.0471325	O
H O	0.735	= 0.048416		..	
H	2.863	= 0.188600		..	

100.000 = 5.555023 having required 5.2708745 cubic mètres of atmospheric air at a temperature of 0° C.

of a circle, of a diameter equal to that of the globule, and its circumscribed square. If, however—as would most generally be the case if the globules were allowed to arrange themselves—the spheres lie together, so that lines joining their centres form equilateral triangles, the “free space” for each globule will only amount to the difference between the sectional area of the globule and the area of its circumscribed hexagon; or, taking the diameter of a globule as being = 1, the “free space” will be $0.8655 - 0.7854 = 0.0801$. Thus, while in the former case the “free space” amounts to 21.46 per cent. of the whole area occupied by the globules, it would in the latter instance amount to but 8.01 per cent.—*Translator.*

If, then, the transverse section of the hearth = 0.0241407 square mètre, the space between the pieces of coke will be $0.0241407 \times 0.2146 = 0.00518$ square mètre; and the velocity per second of the entering air would be:

$$\frac{\text{vol. per hour in cub. mètr.}}{3600 \times \text{section}} = \frac{5.2708745}{3600 \cdot 0.00518} = 0.28265 \text{ mètre.}$$

The volumes of the fuel used in my experiments were:

Height of Layer. Mètre.	Average Section of the Hearth. Square Mètre.		Cubic Mètre.
0.062	$\times 0.0241047$	..	= 0.0014967
0.124	$\times 0.032655$	..	= 0.0040494
0.186	$\times 0.04246$	..	= 0.0078975

The surface of contact for one cubic mètre was

for pieces 35 millimètres in diameter = 90 square mètres

.. 30 ..	..	105 ..
.. 20 ..	..	157 ..

and the surface of contact for the volumes of fuel upon the hearth was:

	Mètre.	d = 35mm. sq. m.	d = 30mm. sq. m.	d = 20mm. sq. m.
Height of the layer of fuel 0.062 the surface =	0.1347	0.15715	0.23498	
" " 0.124 "	0.36444	0.42519	0.63576	
" " 0.186 "	0.71077	0.82924	1.23990	

If we divide the velocity of the entering air by those surfaces of contact, we get the velocity of the air for 1 square mètre of surface of contact.

The proportions expressed by these quotients give the means of deciding whether the combustion is more or less complete; if the velocity is too great the products of the combustion will contain air in an unaltered state; if the velocity, however, is too small, the products contain unconsumed gases.

In order to make the analysis of the products of combustion, I at first tried Bunsen's method; I, however, very soon abandoned it, and I have found that the quantitative analysis is much more useful for such cases, for it allows the current of the gas to be conducted through the apparatus during a whole hour.

Fig. 7 represents the apparatus which I have used for these analyses. The gas to be analyzed was first conducted through the U-tube A filled with chloride of calcium, for absorbing all the steam or vapour mixed with the gas. It next passed through the bulb-tube B, which contained a solution of potash for absorbing the carbonic acid contained in the products of combustion. The tube C, which was next traversed, contained lime slaked in caustic soda, destined to absorb any vapour or carbonic acid which might have escaped from B. The tube D, through which the gas next passed, was filled with a few grammes of phosphorus, which, after having been melted, were distributed over half the inner surface of the tube, whilst the other half towards E was filled with cotton in order to keep back the vapour of the phosphoric acid. This tube D was slightly heated by means of a spirit-lamp, the phosphorus being thus enabled to absorb the free oxygen contained in the gas. The tube E was filled with oxide of copper kept red-hot by means of a small movable furnace of sheet-iron. The oxide of copper being decomposed by the carbonic oxide existing in the gases, produced carbonic acid, which was finally absorbed by the potash in G, after the existing hydrogen had been gradually retained as water by the chloride of calcium in the tube F. The object of the last tube H filled with lime saturated with caustic soda is the same as that of tube C; while J represents the aspirator, in which the nitrogen is accumulated. This aspirator is provided with a manometer, in order that the volume of the nitrogen may be approximately ascertained; and besides, the water running from the aspirator was exactly measured in a reservoir provided with a scale, and the aperture of the tube through which the water must run was such that almost exactly one hour was required for the passage of 2 litres. The products of combustion were passed through the apparatus at the rate of 0.5555 cubic centimètre per second. The 2 litres of water having been run off, a litre of nitrogen was passed through the apparatus after the tube A had been connected with two other tubes, the first of which contained phosphorus, and the second hydrate of potash, and

subsequently atmospheric air was drawn through. In this manner each time that an analysis was made the apparatus was filled with dry nitrogen, and the same operation was performed at the commencement of each analysis.

The apparatus for combustion used in these experiments was a small laboratory furnace with hot-water bath and apparatus for distillation; this furnace is marked A in Fig. 8.

The grate, which consists of a movable frame, is 13 centimètres square, giving a total surface of 0.0169 square mètre: the free space between the fire-bars amounts to one-third of that surface. The width of the hearth above the grate increases gradually, so that an increased height of the fuel upon the grate produces also a larger average transverse section.

The bent tube *a*, passing vertically into the lower part of the chimney B, leads to the pressure gauge C for measuring the exhaustion in the chimney; and an india-rubber pipe fastened sideways to the tube *a*, leads the gases into the apparatus described above. The pressure gauge C was the most sensitive one that could be used for these experiments; but although, owing to its obliquity, 144 millimètres on its scale represented but 1 millimètre of effective pressure, a correct measurement of the exhaustion in the chimney B was scarcely possible, as the capillary attraction sometimes overpowered the chimney draught. The measurement of the temperature in the chimney is of importance for further observations. The piece O confined in the chimney B, contained a thermo-electric element composed of copper and of brass surrounded and isolated by quartz sand. The apparatus *p p*, for cooling one end of the element, and the galvanometer S S, for increasing the current produced, were the same as have been already described.

The sizes of the pieces of fuel placed upon the grate become gradually diminished as combustion goes on; and in order, therefore, to obtain comparable results, it was necessary to maintain the fire for seven or eight hours, and only then to begin with the analysis recorded, when the hearth and chimney were thoroughly warmed. The recorded observations of the temperature in the chimney and the pressure indicated by the

pressure gauge were always obtained during the last five of the seven or eight hours' firing.

In order to keep a constant volume of fuel upon the grate, iron bars were fixed at a certain height in the hearth, so that the layer of fuel could always be kept to that height.

The pieces of fuel were weighed, and every quarter of an hour, at each observation of the pyrometer and of the pressure gauge, the correct level of the fuel in the hearth was restored, and the weight of the added fuel was written down.

The Table on the following pages gives the results of nine experiments with coke, and of three experiments with anthracite.

The following is the calculation of these experiments :

The experiment No. X., for example, gave for the consumption per hour 0·5 kil., which contains 0·4268 kil. of carbon, equal to 0·39787 cubic mètre, besides 0·04957 kil. of water, and 0·01029 kil. of hydrogen.

The analysis of the products of combustion gave,

In volumes, N	77·276
" O	10·981
" CO ²	9·512 = 4·756 C.
" HO	2·231
	<hr/>
	100·000

The proportion between the carbon in the fuel and that in the products of combustion being as 0·39787 to 4·756, the effective volume of the products of the combustion will therefore be

$$\frac{4\cdot756}{0\cdot39787} = \frac{77\cdot276}{x}$$

and we get:

Products of the Combustion formed of:		Atmospheric Air.	
6·4646 cubic mètres	N =	6·4646 cubic mètres	N
0·9186 "	O =	0·9186 "	O
0·7957 "	CO ² =	0·7957 "	O
0·1866 "	HO =	—	
<hr/>		<hr/>	
8·3655 cubic mètres.		8·1789 cubic mètres.	

1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.	13.
Number of the Experiment.	Diameter of the Piece of Coke in millimètres.	Height of Layer in mètres.	Consumption per hour in kila.	Contents of the Fuel in kila.		Volume of the Carbon in mètres.	Analysis of the Products of Combustion Volumes.					
				C	H O		N	O	CO ₂	CO	H O	H

COKE.

I.	35	0.062	0.6	0.519	0.012	0.4888	77.54	12.79	7.77	0	1.99	0
II.	35	0.124	1	0.865	0.020	0.80637	77.93	7.38	13.29	0	1.40	0
III.	35	0.186	1.2	1.038	0.024	0.96764	79.04	0	20.96	0	0	0
IV.	30	0.062	0.6	0.519	0.012	0.4838	77.62	0.584	11.00	0	1.796	0
V.	30	0.124	0.8	0.692	0.016	0.6451	78.427	5.233	15.562	0	0.787	0
VI.	30	0.186	0.8	0.692	0.016	0.6451	78.336	1.066	19.446	0.518	0.486	0.148
VII.	20	0.062	0.6	0.519	0.012	0.4838	77.629	9.208	11.282	0	2.241	0
VIII.	20	0.124	0.8	0.692	0.016	0.6451	76.196	0.620	18.155	1.431	0.785	2.863
IX.	20	0.186	0.8	0.692	0.016	0.6451	69.876	0.439	6.499	23.186	0	0

ANTHRACITE.

X.	25	0.062	0.5	0.4268	0.04957	0.39787	77.276	10.981	9.512	0	2.231	0
XI.	25	0.124	0.8	0.68288	H 0.01029	0.6366	78.048	7.319	11.783	0.538	0.2266	0.5289
XII.	25	0.186	0.8	0.68288	H 0.01646	0.6366	76.679	12.529	7.892	0.068	0.495	2.837
					H 0.07932							
					H 0.01646							

14.	15.	16.	17.	18.	19.	20.	21.	22.
Sum.	Volume of C in the Products.		Volumes of the Products of Combustion per hour, according to analysis.					
	in CO ₂	in CO	N	O	CO ₂	CO	H ₂ O	

COKE.

100	3.885	0	9.6559	1.5927	0.96759	0	0.2366	0
			12.45279					
100	6.645	0	9.4568	0.89556	1.61271	0	0.16989	0
			12.13495					
100	10.480	0	7.2978	0	1.9353	0	0	0
			9.2331					
100	5.500	0	6.8277	0.84303	0.96793	0	0.15798	0
			8.79664					
100	7.781	0	6.5058	0.43385	1.2902	0	0.061103	0
			8.290953					
100	9.723	0.259	5.0626	0.068891	1.25670	0.033477	0.031408	0.00
	9.982		6.4626407					
100	5.641	..	6.6269	0.78972	0.9676	0	0.1922	0
			8.57642					
100	9.0775	0.7155	3.987	0.040842	1.1959	0.094265	0.042416	0.18
	9.7930		5.549023					
100	3.2995	11.593	3.037	0.01908	0.28246	1.0077	0	0
	14.8925		4.34624					

ANTHRACITE.

100	5.756	..	6.6646	0.9186	0.7957	0	0.1866	0
			8.3655					
100	5.8915	0.269	7.5485	0.7563	1.2176	0.0555	0.2266	0.52
	6.1605		10.3334					
100	3.696	0.034	13.087	2.1383	1.2616	0.0116	0.0845	0.48
	3.730		17.0672					

24.	25.	26.	27.	28.	29.	30.	31.
Volume of Air required for these Products at 0° C.			Volume of Air required per second in cubic metres.	Surface of Contact in square metres.	Free space between the Pieces of Fuel; average section in sq. metres.	Velocity of the Air between the Pieces of Fuel in mètre.	Velocity of Air per square metre of Surface of Contact.
O from CO ₂	O from CO	Free O					

COKE.

59	1.5927	0	0.96759	0.00339	0.1347	0.0051725	0.6554	4.864
	12.21619							
38	0.89556	0	1.6127	0.003324	0.3644	0.007008	0.4744	1.302
	11.96506							
78	1.9353	0	0	0.002565	0.71077	0.009112	0.2815	0.39605
	9.2331							
77	0.84303	0	0.96793	0.0023996	0.15715	0.0051725	0.46391	2.952
	8.63866							
58	0.43385	0	1.2902	0.002286	0.42519	0.007008	0.3261	0.7672
	8.22985							
26	1.2567	0.016738	0.068891	0.0017791	0.82924	0.009112	0.19525	0.23546
	6.404929							
69	0.78972	0	0.9676	0.002329	0.23498	0.0051725	0.45027	1.9162
	8.38422							
7	1.1959	0.0471325	0.040842	0.0014641	0.63576	0.007008	0.20892	0.3286
	5.2708745							
7	0.28246	0.50385	0.01908	0.0006673	1.2399	0.009112	0.11713	0.09447
	3.84239							

ANTHRACITE.

346	0.7957	0	0.9186	0.002269	0.1960677	0.0051728	0.4386	2.237
	8.1789							
485	1.2176	0.02775	0.7563	0.002653	0.5304714	0.007008	0.37857	0.7137
	9.55015							
87	1.2616	0.0058	2.1383	0.004581	1.0345725	0.009112	0.5027	0.4859
	16.4927							

whence the volume of air per second = $\frac{8 \cdot 1789}{3600} = 0 \cdot 00227$ cubic mètre.

The surface of contact corresponding with the height of the layer is $0 \cdot 1960677$ square mètre, the free space between the pieces of coke in the average section is $0 \cdot 0051728$ square mètre, the velocity between the pieces therefore = $0 \cdot 4386$ mètre. Then x being the velocity per square mètre of surface of contact, we have $0 \cdot 1960677$ square mètre : 1 square mètre :: $0 \cdot 4386 : x$, whence $x = 2 \cdot 237$ mètres = velocity per square mètre of surface of contact.

If we now arrange the final results of the experiments according to the velocities of the air per square mètre of surface of contact = V , and write below the quantities of combustible gases escaping unconsumed = G , and the surplus of air = L , we get :

	I.	IV.	VII.	II.	V.	VIII.	III.	VI.	IX.
$V =$	4·865	2·952	1·916	1·302	0·767	0·328	0·396	0·235	0·094 mètre.
$L =$	61·0	45·7	43·9	35·2	24·9	2·9	0	5·1	2·2 per cent.
$G =$	0	0	0	0	0	CO 1·431 H 2·863	0	CO 0·518 H 0·184	CO 23·186

Of course an exact coincidence of the results could not be expected, for the surface of contact was only approximately determined; and a less striking coincidence even might have been sufficient under these circumstances.

The following conclusions are derived from these experiments :

1. That perfect combustion depends upon the proportion between the surface of contact and the velocity of the entering air.
2. A velocity of $0 \cdot 39$ mètre per second per square mètre of surface of contact is sufficient for a perfect combustion.
3. The diminution of the velocity allows combustible gases to escape with the products of combustion.
4. When the velocity per square mètre of contact is $0 \cdot 09$, almost all the carbon is transformed into carbonic oxide.

According to our mode of determining the surface of contact

the exterior surface only of the pieces of fuel has been taken into account; the surface is, however, in reality, much greater, as coke is very porous, and this naturally increases greatly the effective surface of contact. Charcoal is still more porous, whilst anthracite and pit coals are not porous but compact; and each fuel will be different in this respect, and will follow a particular law.

In order to demonstrate this, three experiments were made with anthracite, these giving the following results:

	X.		XI.		XII.
V =	2.237	..	0.7137	..	0.4859 mètre.
L =	52.4	..	34.9	..	59.7 per cent.
G =	0	..	CO 0.538	..	CO 0.0116 „
		..	H 5.119	..	H 0.4842 „

The last experiment, however, is not comparable with the others, because after a firing of six hours the hearth contained at such a height of the layer of fuel a greater proportion of slag than of combustible matter.

The experiments X. and XI. are comparable with:

	VII.	and	V.
V =	1.916	..	0.767 mètre.
L =	43.9	..	24.9 per cent.
G =	0	..	0

These results prove that anthracite offers, on account of its compactness, less surface of contact than coke, for the former, with an almost equal velocity of air, allowed a much greater surplus of air to pass away with the products of combustion, than was the case with the latter fuel.

I had intended to pursue these experiments in another and more exact manner, but I found that the influence of the temperature upon the products of combustion is even greater than that of the surface of contact; and I have therefore made this matter the subject of a separate chapter.

CHAPTER IV.

INFLUENCE OF THE TEMPERATURE UPON COMBUSTION.

IN order to continue the researches of the influence of the surface of contact upon different fuels, pieces of fir, beech, and oak were cut into regular small cubes, measuring 5 millimètres on the side, and these cubes were carbonized by heating them in a crucible after they had been mixed and covered with spathic carbonate of iron. Powdered pit coal mixed with gum to a plastic mass was next formed into globules of 5 millimètres diameter, which were also carbonized like the wooden cubes.

These cubes and globules were of a regular form and of an exact size, and they were put into a porcelain tube, 22 millimètres in diameter, which was placed in a furnace in such a manner that the contents of the tube were fully exposed to the fire. One end of the tube remained open, whilst the other end was provided with a cork through which passed a glass tube, communicating with the aspirator (see Figs. 9 and 10) by means of an india-rubber pipe. I used for convenience three of these aspirators, and was thus able to make each time three experiments without interruption; in order to prevent any condensation of the gas drawn off, the aspirators were filled with olive oil.

Fig. 9 represents an elevation, and Fig. 10 a transverse section of the aspirator. The plug of the cock A is provided with a pointer, indicating upon a graduated arc *aa* the area of opening of the cock; this opening of course varies with the position of the pointer, and $2\frac{1}{2}$ litres of oil can thus be drawn off during any period varying between six and sixty minutes. The two cocks B and B' serve for completely confining the gas in the aspirator.

The analysis of the gases was made by means of an apparatus similar to that described in Chapter III. and represented by Fig. 7, with the only difference that the tube D containing phosphorus was omitted, and that the gas, instead of being drawn away by the aspirator T, was forced out of the oil aspirator;

for that purpose, the vessel containing the gas was turned upside down when the descending oil forced out the gas.

The calculation of the results of the analysis was simply as follows:

	Gramme.	Litre.		Litre.
Found CO^2	= 0.7935	= 0.40348	containing	0.40348 O
„ CO	= 0.1340	= 0.10707	„	0.053535 O

Then 0.457015 O.

$$20.96 \text{ O} : 97.04 \text{ N} = 0.457015 \text{ O} : x . \text{ N} = 1.7234 \text{ litres N.}$$

Expressing this in percentages, we have :

	Litres.		Per cent.
0.40348 CO^2	=	18.061	
0.10707 CO	=	4.793	
1.72340 N	=	77.146	
<hr/>			
2.23395	=	100.000	

A great number of such experiments and analyses were made without any comparable results being obtained ; but I observed finally that the temperature, at which the pieces of coal were kept in the tube, had a much greater influence upon the results than the surface of contact.

I then placed the porcelain tube in a muffle, and arranged by the side of it the thermo-electric element in order to ascertain the temperature. The results obtained in this manner were not as exact as I could have desired, but they gave me at least approximate values. The cause of this imperfection may be found in the circumstance that the coal itself contained in its pores condensed air, and that the tube in which the fuel was heated was also at first filled with air, which always produced a certain quantity of carbonic acid, and this remained mixed with the carbonic oxide. A small wooden cylinder, the capacity of which was exactly 13 cubic centimètres, held 100 globules of coke and 92 cubes of charcoal, there being therefore 7.7 globules of coke and 7.08 cubes of charcoal per cubic centimètre. The coke globules contained in 1 cubic centimètre had,

therefore, a surface of contact of $7.7 \times 0.7854 = 6$ square centimètres, while 1 cubic centimètre of charcoal cubes had a surface of contact of $7.08 \times 1.5 = 10.6$ square centimètres.

The porcelain tube had an interior section of 3.801 square centimètres, whence the surface of contact of the pieces of coal contained in the tube could easily be calculated. The quantity of air which passed through the tube per second, divided by the existing surface of contact, gave thus the surface of contact in square centimètres for 1 cubic centimètre of air per second; this quantity I designate C F.

Number of the Experiment.	Analysis of the Products.			CF	Temperatures.
	CO	CO ₂	N		
COKE GLOBULES.					
I.	29.76	2.99	67.25	439.8	871° cold air.
II.	31.42	1.39	66.19	793.0	1000° "
III.	31.54	1.92	66.54	302.4	991° "
IV.	32.21	2.17	65.62	338.7	987° "
V.	32.83	1.09	66.08	1412.7	900° "
VI.	34.08	0.38	65.54	413.3	? Very high—air cold.
BEECH CHARCOAL.					
VII.	32.54	1.69	65.77	349.9	? Air cold.
OAK CHARCOAL.					
VIII.	10.75	14.49	74.76	1420.7	Estimated 500° air cold.
IX.	9.16	15.46	75.38	287.4	? Air cold.
X.	18.06	10.07	71.87	362.6	? " "
XI.	33.27	0.87	65.88	524.8	? " warm.
XII.	26.90	4.72	68.38	344.6	? " cold.
XIII.	31.59	1.89	66.52	390.7	? " "
FIR CHARCOAL.					
XIV.	23.38	6.85	69.77	478.1	932° air warm.
XV.	24.02	6.55	69.43	269.8	930° "
XVI.	24.12	6.40	69.48	390.9	933° "
XVII.	28.09	4.00	67.91	234.9	948° "
XVIII.	31.07	2.20	66.73	370.9	951° "
XIX.	31.69	1.83	66.48	371.1	969° "
XX.	31.89	1.71	66.40	496.7	983° "
XXI.	32.29	1.46	66.25	271.9	1110° "
XXII.	33.49	0.74	65.77	244.0	1126° "
XXIII.	33.92	0.48	65.60	580.3	956° "
XXIV.	33.93	0.47	65.60	341.9	958° "
XXV.	34.64	0	65.36	694.9	1111° "

The particulars of a number of these experiments are given in the preceding Table. In a certain number of them the porcelain tube was placed in the muffle in such a manner that a part of the latter remained empty, thus allowing a preliminary heating of the air before entering the porcelain tube.

The experiments II., V., XI., XXIII., and XXV. represent the case in which the surface of contact was larger than would have been necessary in order to approach the maximum of carbonic oxide in the products, as smaller surfaces of contact gave at similar temperatures equal quantities of carbonic oxide.

The experiment VIII. shows that at the low temperature of 500° C. a very great surface of contact is required in order to transform one-third of the carbon of the gas into carbonic oxide: this case is similar to those mentioned in Chapter III., where the average temperature in the hearth was also about 500° C.

The temperature during the experiment IX. was not observed, but it must have been very high in order to give with a surface of contact of 287·4 a result almost as favourable as experiment VIII.

The mean of the experiments

III. and IV. gives 31·88 per cent. CO, 320·5 CF, and 989°,
 XVIII. „ XIX. „ 31·88 „ CO, 371·0 CF, „ 960°.

These figures, however, cannot be used to establish a comparison between coke and fir charcoal, because with the former the temperature was higher and the surface of contact smaller than with the latter fuel; but we see that the two sorts of fuel comport themselves in the same manner in respect to the relation between surface of contact and temperature.

But the principal object of these experiments was the determination of the volume occupied by the fuel in the furnace itself, at the extreme limit at which all carbonic acid originally produced is reduced to carbonic oxide.

If we compare the experiments

XXIV. 33·93 per cent. CO, 341·9 CF, and T = 958°

XXI. 32·29 „ „ 271·9 „ = 1110°

XXII. 23·49 „ „ 244·0 „ = 1128°

we find that :

$$(1110 - 958) = 152^{\circ} \text{ and } (341.9 - 271.9) = 70.0 \text{ C F.}$$

Therefore 1 square centimètre of surface of contact corresponds

$$\text{to } \frac{152}{70} = 2.17^{\circ} \text{ of temperature, and next:}$$

$$(1126 - 1110) = 16^{\circ} = (271.9 - 244.0) = 27.9 \text{ C F,}$$

whence 1 square centimètre of surface of contact corresponds

$$\text{to } \frac{16}{27.9} = 0.57^{\circ} \text{ of temperature; it thus follows that the sur-}$$

face of contact decreases less quickly than the temperature increases, and that in a geometrical progression. But this progression could not be determined with the small number of experiments which had been made, and I was obliged to employ other means for that purpose.

I put a crucible holding one litre into another crucible of a much larger size, and filled the space of 6 centimètres between the outer surface of the smaller crucible and the inner surface of the larger one with sand; each of the crucibles was provided with a hole at a certain height from the bottom, and a tuyere through which air was blown out of a large reservoir made of glass was placed through both holes. The whole apparatus was then heated by burning fuel in the inner crucible, and when the outer surface of the larger crucible got very hot, I analyzed the products of combustion, always keeping the inner crucible entirely filled with small pieces of coke.

The analyses showed that for 1 cubic centimètre of air introduced upon 10.47 square centimètres of surface of contact 7 to 12 per cent. of carbonic acid were produced to 21 to 13 per cent. of carbonic oxide.

But when a portion of a second crucible forming a conical mouthpiece was placed upon the smaller crucible, thus giving for one volume of air 13.00 square centimètres of surface of contact, the products did not contain any longer carbonic acid, but only carbonic oxide. Unfortunately, the temperature could not be determined with this arrangement, but it was so high that the cinder produced from the coke was liq^{ue} and it

can thus be supposed to have been at least 1200° C. on the average.

But the quotient for the differences $(244 - 13) = 231$ and $(1200 - 1126) = 74$ is $\frac{74}{231} = 0.3346$, and if the surface of contact required in the blast-furnace had to be calculated according to that value, we should find that the surface of contact necessary for a temperature of 1239° C. would be equal to 0. It thus follows that the reduction of carbonic acid and its formation, on account of the high temperature, requires only an indefinitely small surface of contact. The surface of contact required for the production of the carbonic acid is included in all these experiments.

In order now to ascertain what surface of contact is necessary for the formation of carbonic acid, I brought carbonic acid instead of air in contact with the cubes of fir charcoal, and obtained with 806 square centimètres of surface of contact, 98.11 per cent. CO, 1.89 per cent. CO₂, 1785.3 C F and 975° T; with 806 square centimètres of surface of contact, 91.38 per cent. CO, 8.62 per cent. CO₂, 1054.7 C F and 1020° T. But 1 volume of carbonic acid contains 1 volume of oxygen and $\frac{1}{2}$ volume of carbon, whilst 1 volume of air contains 0.21 volume of oxygen and 0.79 volume of nitrogen; the surface of contact 806 has, therefore, to be multiplied by 0.21, and the product thus obtained has again to be divided by the carbonic acid introduced per second, in order to assimilate the results to those obtained with air.

The surface of contact for the temperature of 975° will then be = C F = 384.4 square centimètres, which is almost the same as for the experiments IV. and XX., where we got

$$\begin{array}{l} 338.7 \text{ C F and } 987 \text{ T} \\ \text{and } 371.1 \text{ ,, ,, } 969 \text{ T.} \end{array}$$

The mean of these two experiments, 354.9 C F and 978 T, would thus represent for the formation of the carbonic acid a surface of contact of $384.4 - 354.9 = 29.5$; that is equal to $\frac{1}{13}$ th of the total surface of contact.

It can thus be admitted as highly probable that each cubic mètre of air blown into the blast-furnace per second requires one square mètre of surface of contact for the formation of carbonic acid, and 12 square mètres of surface of contact for the reduction of this acid into carbonic oxide.

CHAPTER V.

MOISTURE IN THE AIR.

ONE cubic mètre of atmospheric air, saturated with vapour of water, contains

At 0° Cent.	..	..	0·0052	kil. of vapour.
„ 5°	„	..	0·0072	„ „
„ 10°	„	..	0·0095	„ „
„ 15°	„	..	0·01283	„ „
„ 20°	„	..	0·01678	„ „
„ 25°	„	..	0·02201	„ „
„ 30°	„	..	0·02851	„ „
„ 35°	„	..	0·03700	„ „

But atmospheric air is only saturated with vapour when the weather is wet, and it contains generally, in a cold winter's day, only 0·00556 kil., and in a hot summer's day 0·01222 kil. of vapour per cubic mètre. If the blowing cylinder, however, is placed together with the steam-engine in the same room, as generally is the case if horizontal engines are used, the temperature of the room ordinarily reaches 35° C., and the air becomes completely saturated with the steam escaping from the engine. Each cubic mètre of air then contains 0·037 kil. of vapour, which must have a disadvantageous influence upon the action of the blast-furnaces, as shall now be proved. If a blast-furnace is supposed to consume per hour 1000 kils. of coke, containing 75 per cent. of carbon, $\frac{750}{3600} = 0·208333$ kil. of carbon will

be consumed per second. In order to transform that quantity of carbon into carbonic oxide, $0\cdot27777 \dots \text{kil.}$ of oxygen = $0\cdot96112 \dots \text{kil.}$ = $0\cdot70682$ cubic mètre of atmospheric air, is required. But 1 cubic mètre of air contains in the present case $0\cdot087$ kil. of vapour, and therefore $0\cdot70682$ cubic mètre of air contains $0\cdot02615$ kil. of vapour (= $0\cdot0029055 \dots \text{kil.}$ of hydrogen), which absorbs, for the transformation into carbonic oxide and hydrogen, $0\cdot0029055 \times 34000 = 98\cdot789$ calories, whilst $0\cdot208333$ kil. of carbon, transformed into carbonic oxide produces $0\cdot208333 \times 2400 = 499\cdot99$ calories. In that case $\frac{1}{2}$ of the heat produced will be absorbed, and instead of

$$\begin{array}{l} 0\cdot48611 \text{ kil. of carbonic oxide} \\ 0\cdot68335 \text{ ,, nitrogen} \end{array} \left. \vphantom{\begin{array}{l} 0\cdot48611 \\ 0\cdot68335 \end{array}} \right\} \begin{array}{l} \text{the specific heat} \\ \text{of which} = \end{array} \left\{ \begin{array}{l} 0\cdot120510 \\ 0\cdot166740 \end{array} \right\} 0\cdot287250$$

we get

$$\begin{array}{l} 0\cdot48611 \text{ kil. of carbonic oxide} \\ 0\cdot00290 \text{ ,, hydrogen} \\ 0\cdot60683 \text{ ,, nitrogen} \end{array} \left. \vphantom{\begin{array}{l} 0\cdot48611 \\ 0\cdot00290 \\ 0\cdot60683 \end{array}} \right\} \begin{array}{l} \text{the specific heat} \\ \text{of which} = \end{array} \left\{ \begin{array}{l} 0\cdot120510 \\ 0\cdot009892 \\ 0\cdot148060 \end{array} \right\} 0\cdot278462$$

$$\text{therefore, the temperature for dry air} = \frac{499\cdot99}{0\cdot287250} = 1740^{\circ},$$

$$\text{and for moist air only} \quad \dots \dots \dots = \frac{401\cdot20}{0\cdot278462} = 1441^{\circ}.$$

The example chosen for showing the influence of humidity may be exaggerated; but the above observations prove, nevertheless, that an alteration in the amount of humidity may cause a change in the production of heat, which is sufficient not only to modify but even to interrupt the action of the blast-furnace. This also explains the observation of metallurgists, that the same charge in the blast-furnace requires less coal in the winter than in the summer.

CHAPTER VI.

ELEVATION OF TEMPERATURE BY THE PRESSURE OF THE BLAST.

THE temperature of the products of combustion depends, as has been already shown, upon the volume over which the produced heat is distributed; if the volume is diminished, the temperature necessarily increases.

If W represents the quantity of heat produced,
 w the specific heat of the products of combustion,
 B the barometric pressure (in mètres of mercury),
 p the manometric pressure,
 and T'' the resulting temperature, we get

$$T'' = \frac{W}{w} \cdot \left(1 + \frac{p}{B}\right).$$

If $W = 8000$, $w = 2.8571$, $p = 0.03$, and $B = 0.76$, then

$$T'' = \frac{8000}{2.8571} \cdot \left(1 + \frac{0.03}{0.76}\right) = 2910^{\circ} \text{ C.}$$

If the manometric pressure = 0.09 or 0.18 : then

$$T'' = \frac{8000}{2.8571} \cdot \left(1 + \frac{0.09}{0.76}\right) = 3131^{\circ} \text{ C.}$$

$$\text{or } T'' = \frac{8000}{2.8571} \cdot \left(1 + \frac{0.18}{0.76}\right) = 3463^{\circ} \text{ C.}$$

Of course such a compression does not produce heat, and the elevation of the temperature is only local, for it diminishes in proportion as the gases ascend in the furnace, until it becomes *nil* on arriving at the throat.

The effect of this elevation of temperature, which shows itself especially on the hearth of the furnace, is a more rapid consumption of the carbon, and therefore an augmentation of the charge. But this elevation of the temperature in the furnace also effects the direct reduction of the oxides contained in the ores, by means of solid carbon, and it favours at the same

time (as any elevation of the temperature at the lower part of the furnace always does) the reduction of the earths, silicious acid, phosphorus, &c., which can only combine with the iron in a reduced state.

The degree of pressure of the blast, however, cannot in most cases be arbitrary, but is determined by the resistance of the column of fusion; if, therefore, a reduction of the pressure of the blast is required, the resistance of the column of fusion must necessarily be diminished. But great pressures of blast offer two other disadvantages besides the one mentioned above; and I might almost say it is fortunate that they exist, or else many metallurgists would be tempted to use excessive pressures in order to increase the charge, without considering the deterioration of the product.

One of these disadvantages is the circumstance that the gases which effect the reduction of the ores in the shaft of the furnace do not, if a high-pressure blast be used, fill in an uniform manner the spaces between the pieces of the charge; wide passages are formed, through which the gases rise without penetrating the neighbouring materials; and these untouched ores, after having lost their support through the melting of the material underneath, at once fall down in smaller or greater quantities, and barricade, if in a half-molten state, the passage for the rising gases, the action of the furnace being thus suspended. If the falling quantity is only small, it melts on the hearth without being further reduced, and the process becomes irregular; but the existing temperature allows a certain direct reduction, which again absorbs heat, and which produces finally a cooling action, unless an energetic remedy be applied. The other disadvantage of a very high pressure of the blast, which does not, however, occur very often, is the burning away of the pig-iron itself; the temperature then rises quickly in the whole shaft, for the heat which 1 kil. of the burning iron develops amounts to 1276 calories. Although such an occurrence can soon be remedied, it is nevertheless a disturbance, and it may easily happen that another derangement follows, by the furnace passing from one extreme state into the other.

CHAPTER VII.

ELEVATION OF THE TEMPERATURE BY A PRELIMINARY HEATING
OF THE FUEL.

THE circumstance that the hot gases rise in the shaft of the blast-furnace from the bottom to the top, whence the charge in descending acquires a gradually-increasing temperature, is a very efficacious means of increasing considerably the temperature produced by the combustion.

If T represents the primitive temperature, S the specific heat of the fuel at that temperature, w the specific heat of the products of the combustion, and T' the resulting temperature, we get:

$$T' = T \cdot \frac{1}{1 - \frac{S}{w}}.$$

If we suppose, for example, the temperature of combustion of 1 kil. of coke which contains 75 per cent. of carbon to be equal to 2713°C ., the specific heat of coke at that temperature (see Chapter X.) to be $= 0.66082$, and the value of $w = 2.21185$; then

$$T' = 2713 \cdot \frac{1}{1 - \frac{0.66082}{2.21185}} = 3869^{\circ}\text{C}.$$

If the fuel, however, were charcoal, containing 90 per cent. of carbon, then $S = 0.30907$, $w = 2.654226$, and therefore

$$T' = 2713 \cdot \frac{1}{1 - \frac{0.30907}{2.654226}} = 3070^{\circ}\text{C}.$$

In order to find the quantity of heat contained in the gases, the fuel consumed per second has simply to be multiplied by w and by the temperature. We thus find, under the above suppo-

sition, that the fuel consumed per second is in each case 1 kil.: $w.3869 = 8557$ calories, and $w.3070 = 8150$ calories; the preliminary heating of the fuel has therefore added 2557 calories in the first case, and 949 calories in the second instance.

CHAPTER VIII.

QUANTITY AND INTENSITY OF THE HEAT.

ONE kilogramme of carbon requires for its transformation into carbonic acid $6 : 1 :: 16 : x = 2.6666 \dots$ kils. of oxygen = $\frac{2.6666}{1.43028} = 1.8654$ cubic mètre, with which, if the oxygen of the air is used as usual, $1.8645 : 20.96 :: 79.04 : x = 7.0309$ cubic mètres = 8.8347 kils. of nitrogen will be carried away with the products of combustion.

One kil. of carbon burnt to carbonic acid develops 8000 calories; and that quantity of heat is called the calorific equivalent of the combustible. The products of combustion consist of $1 \text{ C} + 2.6666 \dots \text{O} = 3.6666 \dots$ kils. CO^2 and 12.865 kils. N.

The specific heat of these products is :

$$\left. \begin{array}{l} \text{C O}^2 3.6666 \times 0.2164 = 0.79344 \\ \text{N } 8.8347 \times 0.2440 = 2.15570 \end{array} \right\} = 2.94914;$$

and if we divide the quantity of heat produced by this specific heat, we obtain the temperature arising from the combustion,

which is equal to $\frac{8000}{2.94914} = 2712.7^\circ \text{C.}$; this temperature, there-

fore, also expresses the intensity of the fire.

If this kilogramme of carbon was burnt with pure oxygen instead of air, the quantity of heat developed would remain exactly the same, whilst the intensity of the fire would be considerably increased, for the nitrogen would no longer increase the

volume of the products of combustion, and no other dilution taking place, the intensity in this case would therefore be

$$\frac{8000}{0.79344} = 10082.8^{\circ} \text{C.},$$

or almost four times as great as before.

Wood consists of 50 per cent. of water, a very little hydrogen, and almost 50 per cent. of carbon. Admitting for our demonstration that 1 kil. of wood contains 50 per cent. C and 50 per cent. H O, we require for the generation of the same quantity of heat as above 2 kils. of wood, and the products of combustion consist then of

3.6666 kils. of carbonic acid, the specific	}	
heat of which = 0.79344		
8.8347 kils. of nitrogen, the specific heat		
of which = 2.15570		
1.0000 kil. of steam, the specific heat		
of which = 0.47500		3.42414,

whence the intensity of the fire = $\frac{8000}{3.42414} = 2336.4^{\circ} \text{C.}$, a tem-

perature, however, which will be still further diminished by the latent heat of the water = 536.67; we get thus

$$\frac{8000 - 536.67}{3.42414} = 2179^{\circ} \text{C.}$$

But pure oxygen gas cannot at present be produced at such a rate as will allow of its application for the generation of heat for metallurgical and industrial purposes; and as an increase of the intensity of the heat obtainable is, however, in many cases desirable, I have studied a method of working which renders such an increase possible.

This method consists in the partial elimination of the nitrogen by burning pure carbonic oxide with air; the products of combustion thus obtained when brought into contact with solid

carbon again forming carbonic oxide, which is then burnt a second time.

0.5 kil. of carbon corresponds with 1.1666 kil. of carbonic oxide.
 For its combustion is required 0.6666 „ oxygen,
 which is supplied by a quantity
 of atmospheric air containing 2.2087 „ nitrogen.
 We get, therefore 1.8333 „ carbonic acid,
 which form, by the absorption
 of 0.5 kil. of carbon .. 2.3333 „ carbonic oxide,
 requiring for their combustion 1.3333 „ oxygen,
 which will be mixed with .. 4.4174 „ nitrogen,
 and the products of combustion last obtained contain

3.6666 kils. of carbonic acid } the specific heat of which =
 6.6261 „ nitrogen }

$$\left\{ \begin{array}{l} 3.6666 \times 0.2164 = 0.79344 \\ 6.6261 \times 0.2440 = 1.61680 \end{array} \right\} 2.41044.$$

But if the 1.1666 kil. of carbonic oxide originally burnt are cold, as might be the case in some methods of production, the heat generated is only that which corresponds to the combustion of the carbonic oxide formed by treating the products of the first combustion with the solid carbon, that is to say 2.3333 kils. $\times 2400 = 5599.9$ calories; for the heat produced by the combustion of the first 1.1666 kil. of carbonic oxide is again rendered latent in reducing into carbonic oxide the carbonic acid produced.

But if we divide the quantity of heat produced by the specific heat of the products, we obtain for the temperature only

$$\frac{5599.9}{2.41024} = 2323^{\circ} \text{C.};$$

this being less therefore than with direct combustion, which gave $T = 2712^{\circ} \text{C.}$

But if we give to the 1.1666 kil. of carbonic oxide and the 0.6666 kil. of O + 2.2087 kils. of N, = 2.8753 kils. of air,

necessary for the combustion of the carbonic oxide, the temperature of 500° , which may easily be done, we add

$$1.1666 \times 0.2479 \times 500 = 144.6 \text{ calories.}$$

$$2.8753 \times 0.2377 \times 500 = 341.7 \quad "$$

altogether 486.3 calories;

and if we also raise the temperature of the air, requisite for the second combustion, by the same

amount, the total quantity will be still further

enlarged by $(4.4174 \times 1.3333) \times 0.2377 \times 500 = 683.5 \text{ calories,}$

which, added to the preceding quantities, make 1169.8 calories,

and we get $\frac{5599.9 + 1169.8}{2.41024} = 2808^{\circ} \text{C.}$

The reader will ask whether this augmentation of the intensity by 96°C. is proportionate to the consumption which such an extended operation must require. I simply answer that cases occur, as for example in the melting of the steel, in which even an elevation of the temperature by only 96°C. is already of great value; and that not only has this increase of the temperature to be taken into account, but also the fact that the volumes of the products of combustion for the corresponding temperatures are in the proportion of $97.3:80.6$, and that in the latter case the velocity of the current of the products of combustion can be, therefore, under similar circumstances, greater by $\frac{1}{3}$ th, which is important.

Moreover, this method of working has a very great value in cases where, as in the blast-furnace, the proportion between the nitrogen and carbonic oxide influences the process of reduction.

CHAPTER IX.

VOLUMES OF THE MATERIALS WITH WHICH THE BLAST-FURNACE
IS CHARGED.

It is a fact that the weight of homogenous materials of approximately equal pieces, if occupying the same volume, remains unaltered whether these pieces are great or small. This fact is easily explained.

If we suppose the isolated pieces, which for example occupy the space of 1 cubic mètre, to be spheres, the number of these spheres will be $= n^3 = \left(\frac{l}{d}\right)^3$, if l represents the side of the cube (1 cubic mètre in the present example) and d the diameter of the spheres.* Taking now the diameter d of the spheres to be 0.03 mètre, and l , as already stated, equal to 1 mètre, the number of the balls will be

$$\left(\frac{1}{0.03}\right)^3 = 37037.$$

The volume of one of these spheres is $d^3 \frac{\pi}{6} = 0.0000141372$ cubic mètre. Let now these balls consist of coke, weighing in pieces 400 kils. per cubic mètre; then representing this weight by G , the specific weight of this coke will be

$$\frac{G}{\left(\frac{l}{d}\right)^3 \cdot d^3 \cdot \frac{\pi}{6}} = \frac{400}{37037 \times 0.0000141372} = 763.94;$$

that is to say, 1 cubic mètre of coke in one piece would weigh 763.94 kils., or taking water equal to 1, the specific gravity of this coke is = 0.76394. If, however, the specific gravity of the coke = S is known, then the weight $G = 1000 S \cdot n^3 \cdot d^3 \cdot \frac{\pi}{6}$;

* These calculations are made on the supposition that lines joining the centres of the spheres would form the outlines of cubes. See footnote to page 15.—*Trans.*

that is to say $1000 \times 0.76394 \times 37037 \times 0.03^3 \times \frac{\pi}{6} = 400$ kils.

With spheres of 0.1 mètre diameter, the formula gives also $1000 \times 0.76394 \times 1000 \times 0.1^3 \times \frac{\pi}{6} = 400$ kils.

It is, therefore, quite indifferent whether the diameter of the balls is large or small, the volume of 1 cubic mètre will always weigh 400 kils., it being supposed that the specific weight is constant. The following Table, for the weight of different materials per cubic mètre, is calculated in this manner ; it serves for setting off the volume of the charges.

	Specific Gravity.	Weight per cubic mètre in kils.
Coke	0.75869	400
Pit coal	1.226 to 1.362	642 to 713
Anthracite	1.270 „ 1.919	665 „ 1000
Fir charcoal	0.38197 „ 0.40117	200 „ 210
Oak and beech charcoal ..	0.45836 „ 0.47746	240 „ 250
Birch charcoal	0.42017 „ 0.43927	220 „ 230
Magnetic iron ores	5.3 „ 6	2775 „ 3142
Iron glance	5 „ 5.3	2618 „ 2775
Red hematite	4.7 „ 5.3	6461 „ 2775
Brown „	3.94 „ 4.02	2063 „ 2105
Spathic iron ore	3.6 „ 3.9	1885 „ 2042
Limestone	2.252 „ 2.837	1179 „ 1485
Calcined lime	2.075	1086

CHAPTER X.

SPECIFIC HEATS OF THE MATERIALS WITH WHICH BLAST-FURNACES ARE CHARGED.

THE first application of the pyrometer which I had to make, was the determination of the specific heats of the materials with which a blast-furnace is charged. It is known that the specific heats of solid bodies increase with the temperature, but this increase has only been determined for very few materials, and for a maximum temperature that does not exceed that of boiling mercury, that is to say, 358.5° C. It is, however, indispensable, in order that the operations which go on in the blast-furnace may

be understood, and in order that the manner in which the heat is utilized in the latter may be demonstrated, to know the specific heats of the materials at such temperatures as exist in the blast-furnace itself.

I had no intention of obtaining in this determination results of the greatest exactness, for the materials upon which I had to operate had no constant composition; and I confined myself, therefore, to the following mode of proceeding:—I placed the material—in a state of powder, or in very small pieces—in a small cylinder of very fine iron wire, the weight of which I ascertained in order to take it into account in the calculations. This cylinder, open at the top, was placed with its other end in a larger tube of wrought iron, which was also open at one end and closed at the other. To this closed bottom was fixed a very narrow tube 0·30 mètre in length, which, being provided at the end with a wooden haft, served as a handle for the larger tube.

This receptacle was then introduced into a tubular muffle, in such a manner that its extreme top end coincided exactly with the middle of the length of the muffle; and the thermo-electric element of the pyrometer was introduced from the other end of the muffle, and occupied exactly a similar place to the substance which was to be examined.

The tubular muffle was then heated to the temperature at which the specific heat of the substance had to be determined; and after this temperature had been noted, the tube with the substance was taken out, and the latter, with the wire cylinder, was thrown into water. In order to facilitate operations and to secure the getting out of the wire cylinder, a thin iron rod was introduced into the narrow tube which served as a handle for the larger tube, and the wire cylinder could be thus pushed out of the tube in a very convenient manner.

The cylindrical vessel which contained the water had on one side a recess of 6 centimètres for the reception of the thermometer; and this recess was protected by means of a wire grating, arranged in such a manner that the thermometer could not sustain any damage when the water with the substance cast into it was

quickly stirred. The vessel, which was made of brass, was provided at the top with a rim, by means of which the whole vessel was inserted in a small wooden box, in order to prevent cooling taking place from the outside. The thermometer was a very exact one, divided into fifths of a degree.

The vessel for the water weighed 312 grammes, and as 1 gramme of brass absorbs 0·0939 calorie, while 1 gramme of water absorbs 1 calorie for each rise of temperature of 1°,

The equivalent of this vessel in water is 29·2968 gr.

The equivalent of the thermometer in water is:

For the mercury 0·4393 „

For the glass 1·7877 „

finally the water, which was measured each time

by means of a graduated bottle, weighed .. 1275·0000 „

The calorific capacity of the apparatus was, } 1306·5238 gr.
therefore }

The difference of the temperatures of the water before and after the experiment = t , which, multiplied by the number given above, served for the determination of the quantity of heat supplied by the material which had been used in the experiment.

The weight of the small wire cylinder multiplied by the specific heat of the iron at the temperature of the muffle, and consequently also of the cylinder, had, however, to be deducted from this quantity. After deducting this value for the cylinder, the remainder, multiplied by the weight of the substance and divided by its temperature, gives of course the specific heat of the substance.

For example, red spathic iron ores, previously roasted, gave $t = 4·1^{\circ}\text{C}$., therefore:

$$\begin{array}{rcl} & 1306\cdot5238 \times 4\cdot1 = 5356\cdot650 & \\ \text{and deducting for wire} & \left. \begin{array}{l} \\ \end{array} \right\} 7\cdot4 \times 0\cdot152 = 1\cdot125 & \\ \text{cylinder} & & \\ & \hline & 5355\cdot525 & \end{array}$$

The temperature of the muffle was 1078° , and as the weight

of the substance was 18·2 grammes, the specific heat at that temperature therefore was

$$= \frac{5355 \cdot 525}{18 \cdot 2 \times 1078} = 0 \cdot 272965.$$

The specific heat of this mineral at 100° was deducted from that found at high temperatures, and from this difference was calculated the difference for each 100° of temperature.

The following values have been obtained in this manner:—

	Specific Gravity.	Weight per cubic metre in kila.	Difference per 100° C.	Specific Heat at 100° C.
Beech charcoal	0·4679	245	0·0026	0·24150
Coke from Saarbrück ..	1·1194	586	0·019372	0·157139
Limestone	2·52525	1322	0·0710926	0·1666452
„ (calcined)	2·075	1086	0·0107899	0·2169
Quartz (from the Rhine) ..	2·5939	1358	0·0123295	0·19132
Metallic iron	7·8	4082	0·004005	0·11379

BLACKBAND ORES, FROM J. G. ENKEN, AT MÜHLHEIM, ON THE RUHR.

Blackband ironstone, roasted	2·503226	1310	0·004249 (negative)	0·255747
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WITTELBACH ORES, FROM THE KORNZECH, NEAR GOMBACH-SIEGEN.

Red spathic iron ores (not roasted)	3·679487	1926	0·0846247	0·111740
Red spathic iron ores (roasted)	4·413333	2310	0·013703	0·1530064

ORES FROM SCHMIEDBERG, NEAR GOSERACH-SIEGEN.

Iron glance	4·6105263	2414	0·0122414	0·072182
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KORNZECH, NEAR GOSSELBACH-NIEDERSCHULDEN-SIEGEN.

Spathic iron ore, raw ..	3·35555	1862	0·045845	0·124778
Spathic iron ore, roasted ..	4·460	2335	0·008048	0·179547

HEBBORN AND GUSTAVE-ADOLPHE MINES, NEAR BERG-GLADBACH, NEAR COLOGNE.

Oolitic ironstone, raw ..	3·2380952	1695	0·0033083	0·1894139
„ roasted ..	3·8222222	2001	0·0140863	0·1763226
Manganesian iron ore, from Orefeld, raw	2·813333	1473	—	—
Manganesian iron ore, from Orefeld, roasted	3·085714	1615	0·0204975	0·2353656

MINE SCHWARZE KRUX, AT SCHMIEDEFELD-THURINGIA.

	Specific Gravity.	Weight per cubic metre in kila.	Difference per 100° C.	Specific Heat at 100° C.
Magnetic iron ore	4·2200	2209	0·00712555	0·1667419

WALDHAUSEN-WILBERG MINE, NASSAU.

Red iron ore	3·7750	1976	0·009595	0·171528
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ALLUVIAL ORES FROM HOLLAND.

Raw ores	2·8555	1495	—	0·2183325
Roasted ores	4·360	2283	0·013275	0·1523629

WÜRG ENGEL MINE, NEAR STOCKHAUSEN-LEUN-NASSAU.

Manganesian iron ores, raw	3·4933	1829	—	0·1832221
„ „ roasted	3·6600	1916	0·0085665	0·1440624

SCHMIEDBERG MINES, NEAR GÖSEBACH-SIEGEN.

Magnetic iron ores, raw ..	3·6700	1922	—	—
„ „ roasted	4·64762	2433	0·0084523	0·1522431
Spiegeleisen	7·462963	3908	0·006349	0·0893755
Foundry pig-iron, finely grained	7·05000	3691	0·0039991	0·0904970
Slag from the blast-furnace	2·38333	1248	0·0100948	0·146986
„ „	2·917647	1528	0·0116103	0·1479269
„ „	2·777	1454	0·011796	0·1492089
Slag from the blast-furnace, Hayange	2·575	1348	0·0125077	0·1469854

The following Table gives the specific heats of a few of these materials for different temperatures. These materials are:—

- I. Beech charcoal.
- II. Coke from Saarbrück.
- III. Limestone.
- IV. Calcined lime.
- V. Red iron ore.
- VI. Magnetic iron ore, from the mines of Schmiedberg (roasted).
- VII. Foundry pig-iron finely grained.
- VIII. Spiegeleisen.
- IX. Slag from Hayange.

It has to be taken into consideration that charcoal at 100° C. has a higher specific heat than the specific heat of the latter becomes twice as great as that of the form

SPECIFIC HEATS OF THE CHARGES.

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Tempe- ratures.	I.	II.	III.	IV.	V.	VI.	VII.	VIII.	IX.
100	0.24150	0.157189	0.166645	0.21690	0.171528	0.152243
150	0.24280	0.166825	0.202191	0.22229	0.126325	0.156469	..	..	..
200	0.24410	0.176511	0.237788	0.22769	0.181123	0.160695	..	..	..
250	0.24539	0.186197	0.273284	0.23308	0.185920	0.164921	..	..	..
300	0.24669	0.195884	0.308830	0.23848	0.190718	0.169147	..	..	..
350	0.24799	0.205571	0.344376	0.24388	0.195515	0.173873	..	..	..
400	0.24929	0.215258	0.379923	0.24927	0.200313	0.177600	..	..	..
450	0.25059	0.224945	0.415469	0.25466	0.205110	0.181826	..	..	..
500	0.25189	0.234632	0.451015	0.26006	0.209908	0.186052	..	..	..
550	0.25319	0.244319	0.486561	0.26545	0.214705	0.190278	..	..	..
600	0.25449	0.254006	0.522108	0.27085	0.219503	0.194504	..	..	..
650	0.25579	0.263093	0.557654	0.27624	0.224300	0.198730	..	..	..
700	0.25709	0.273380	0.593201	0.28164	0.229098	0.202957	..	..	..
750	0.25838	0.283067	0.628747	0.28703	0.233895	0.207183	..	..	..
800	0.25968	0.292753	0.664203	0.29243	0.238693	0.211409	..	..	..
850	0.26098	0.302439	0.699688	0.29782	0.243290	0.215635	..	..	..
900	0.26228	0.312125	0.735083	0.30322	0.247988	0.219861	..	0.149691	0.2595547
950	0.26358	0.321811	..	0.30861	0.252635	0.224087	..	0.152865	0.2658393
1000	0.26488	0.331497	..	0.31401	0.257283	0.228314	..	0.156040	..
1050	0.26618	0.341183	..	0.31940	0.261900	0.232540	..	..	..
1100	0.26748	0.350869	..	0.32480	0.266518	0.236766	0.130488	0.159214	0.2721239
1150	0.26879	0.360555	..	0.33019	0.271195	0.240992	0.132487	0.162389	0.278317
1200	0.27009	0.370241	..	0.33559	0.275873	0.245218	0.134487	0.165563	0.284570
1250	0.27138	0.379927	..	0.34099	0.280551	..	..	0.168737	0.290824
1300	0.27268	0.389613	..	..	..	..	0.138486	0.171912	0.297078
1350	0.27398	0.399299	..	..	..	..	0.140485	0.175086	0.303331
1400	0.27528	0.408985	..	..	..	..	0.142485	0.178261	0.309585
1450	0.27658	0.418671	..	..	..	..	0.144484	0.181435	0.315839

TABLE—continued.

Tempe- ratures.	I.	II.	III.	IV.	V.	VI.	VII.	VIII.	IX.
1500	0.27788	0.428357	..	..	..	..	0.146484	0.184610	0.322093
1550	0.27918	0.438043	..	..	..	..	0.148478	0.187784	0.328346
1600	0.28048	0.447729	..	..	..	..	0.150473	0.190959	0.334600
1650	0.28178	0.457415	..	..	..	..	0.152472	0.194133	0.340854
1700	0.28308	0.467101	..	..	..	..	0.154472	0.197308	0.347108
1750	0.28437	0.476787	..	..	..	..	0.156471	0.200482	0.353362
1800	0.28567	0.486473	..	..	..	..	0.158471	0.203657	0.359616
1850	0.28697	0.496159	..	..	..	..	0.161470	0.206831	0.365869
1900	0.28827	0.505845	..	..	..	..	0.162470	0.210006	0.372123
1950	0.28957	0.515531	..	..	..	..	0.164469	0.213180	0.378377
2000	0.29087	0.525217	..	..	..	..	0.166469	0.216355	0.384631
2050	0.29217	0.534903	..	..	..	..	..	..	..
2100	0.29347	0.544589	..	..	..	..	..	..	..
2150	0.29477	0.554275	..	..	..	..	..	..	..
2200	0.29607	0.563961	..	..	..	..	..	..	..
2250	0.29737	0.573647	..	..	..	..	..	..	..
2300	0.29867	0.583333	..	..	..	..	..	..	..
2350	0.29997	0.593019	..	..	..	..	..	..	..
2400	0.30127	0.602705	..	..	..	..	..	..	..
2450	0.30257	0.612391	..	..	..	..	..	..	..
2500	0.30387	0.622077	..	..	..	..	..	..	..
2550	0.30517	0.631763	..	..	..	..	..	..	..
2600	0.30647	0.641449	..	..	..	..	..	..	..
2650	0.30777	0.651135	..	..	..	..	..	..	..
2700	0.30907	0.660821	..	..	..	..	..	..	..
2750	0.31037	0.670507	..	..	..	..	..	..	..
2800	0.31167	0.680193	..	..	..	..	..	..	..

CHAPTER XI.

LATENT HEAT.

THE latent heat of any body is the quantity of heat which that body, if solid or liquid, requires for its transformation into the liquid and gaseous states respectively. Thus, if liquid carbonic acid becomes a vapour, it is latent heat that is restored to it; but if carbonate of lime is decomposed by heat into carbonic acid and lime, it is the heat of combination which is added to the carbonic acid, for the latter in a free state, and at the ordinary temperature, exists only as a vapour. In the blast-furnace not only the water, contained in the charges, but also the iron and the materials producing the slags absorb latent heat, this heat serving for vaporizing the former and liquefying the latter.

The latent heat of steam is exactly known; it is, according to Regnault = 536·67, that is to say, 1 kil. of boiling water absorbs 536·67 calories for its transformation into steam. The latent heat of cast iron as well as that of the slags is, however, almost unknown, and so far science has not shown how these data can be exactly determined.

It has been proved that the latent heat of the metals is proportionate to their elasticity; but the elasticity of cast iron varies so greatly that no satisfactory starting-point is afforded.

According to P. A. Daguin, the latent heat of metals being denoted by L :

$$L = 160 + T \cdot (C - c),$$

in which formula T is the melting-point of the metal, in centigrade degrees, C the specific heat of the molten material at this temperature, and c the specific heat of the solid metal.

Now, Pouillet has stated that the melting-point of easily-liquefied white pig-iron and other less easily fusible kinds varies from 1050° to 1100° C.; and I, on the other hand, have found the specific heat of white iron at these temperatures (see Chap. X.)

$$\begin{aligned} \text{to be} &= 0\cdot0893755 + (10\cdot5 \times 0\cdot006349) = 0\cdot1560400 \\ \text{and} &= 0\cdot0893755 + (11\cdot0 \times 0\cdot006349) = 0\cdot1595940 \end{aligned}$$

whence the differences

$$\begin{aligned} C - c &= 0.1560400 - 0.0893755 = 0.0666645 \\ \text{and} &= 0.1595940 - 0.0893755 = 0.0702185; \end{aligned}$$

the latent heat would thus be =

$$\left. \begin{aligned} 160 + (1050 \times 0.0666645) &= 230 \\ 160 + (1100 \times 0.0702185) &= 237 \end{aligned} \right\} \text{average} = 233.5.$$

Pouillet gives the melting-points of foundry iron as between 1100° and 1250° C., and the specific heat at these temperatures is, according to my determinations :

$$\begin{aligned} 0.0904970 + (11.0 \times 0.0039991) &= 0.1344871, \\ \text{and } 0.0904970 + (12.5 \times 0.0039991) &= 0.14048575, \\ \text{the differences } C - c &= 0.1344871 - 0.0904970 = 0.0439901, \\ &= 0.14048575 - 0.0904970 = 0.04998875, \end{aligned}$$

whence the latent heat =

$$\left. \begin{aligned} 160 + (1100 \times 0.0439901) &= 208 \\ 160 + (1250 \times 0.04998875) &= 222.9 \end{aligned} \right\} \text{average} = 215.45.$$

For the latent heat of the slags we have no formula, but Boulanger and Dulait took from the hearth the slags of white pig-iron and those of the foundry iron, and they cast these slags into a quantity of water the weight of which was known, when the elevation of the temperature of the water showed that the slags of the white pig-iron contained 433 calories, whilst the slags of the foundry iron contained 492 calories.

The melting-point of these slags is scarcely above 1250° C., and the specific heats could probably be calculated thus :

$$\frac{433}{1250} = 0.3464 \text{ and } \frac{492}{1250} = 0.3936.$$

I have found by my experiments the specific heat for four different slags =

$$\left. \begin{aligned} 0.1469360 \\ 0.1479269 \\ 0.1492089 \\ 0.1469854 \end{aligned} \right\} \begin{array}{l} \text{at } 100^{\circ} \text{ the} \\ \text{average} \end{array} = 0.1477643, \quad \text{and} \quad \left. \begin{aligned} 0.27312100 \\ 0.29305565 \\ 0.29665890 \\ 0.30333165 \end{aligned} \right\} \begin{array}{l} \text{at } 1250^{\circ} \text{ the} \\ \text{average} \end{array} = 0.2915418.$$

Subtracting now their specific heat at the melting-point

from the quantity of heat contained in the slags per 1°C. , we get:

$$0.3464 - 0.2915418 = 0.0548582$$

$$0.3936 - 0.2915418 = 0.1020582;$$

and the latent heat would then be

$$0.0548582 \times 1250 = 68.5$$

$$0.1020582 \times 1250 = 122.9.$$

However, it is not admissible that the slag of grey iron should have a specific heat almost twice as great as that of the slag of white iron, but of course the latter had a higher temperature above the melting-point than the former one, and this temperature increased the amount of heat transferred to the water.

But as the slag of the white pig-iron contained free heat, we may take the number 60 as an approximate value for the latent heat of the slags; I consider this number to be more correct than 233 and 205.5 for the latent heat of the cast iron.

I really believe that the method of determination just mentioned is the more correct and deserves the preference, notwithstanding the uncertainty with respect to the amount of free heat contained in the materials. Boulanger and Dulait mixed white pig-iron and grey pig-iron with water, and found the calorific capacity per 1° temperature to be:

$$\frac{309}{1050} = 0.294285; \quad \frac{309}{1100} = 0.280909; \quad \frac{337}{1100} = 0.3063063;$$

$$\frac{337}{1250} = 0.2696000,$$

whence the specific heat at these temperatures =

$$\frac{0.156040}{0.138245} \times 1050 = 145.157 \quad \frac{0.159594}{0.121315} \times 1100 = 133.646$$

$$\frac{0.1344871}{0.1718192} \times 1100 = 189.001 \quad \frac{0.14048575}{0.12911425} \times 1250 = 161.392,$$

latent heat of white pig-iron, on the average 139

„ grey pig-iron, „ .. 175;

numbers which we shall adopt as the more probable ones.

CHAPTER XII.

THE HEAT OF COMBINATION.

WHEN two elements combine chemically with each other, heat is set free; the quantity of the heat thus liberated depending upon the nature of the elements and the proportions in which they enter into combination.

One kilogramme of hydrogen, burnt to water, releases 34000 calories, whilst one kilogramme of sulphur releases only 2220 calories.

One kilogramme of carbon develops 2400 calories, if transformed into carbonic oxide, but if it burns to CO_2 the quantity of heat produced is 8000 calories.

If a thin vessel which contains caustic lime be dipped into a large quantity of water, the weight and temperature of which are known, and a rapid current of carbonic acid, which will soon saturate the hydrate of lime, be then introduced, the elevation of the temperature of the water will show the quantity of heat thus developed—that is to say, the heat of combination of the lime and carbonic acid—from which the correct proportions per kilogramme of the lime may be obtained. I have in this manner found it to equal 197·1 calories.

There are in the blast-furnace five cases in which the heat of combination has to be taken into consideration, namely:—

1. The combustion of the carbon to carbonic acid;
2. The reduction of the carbonic acid to carbonic oxide;
3. The decomposition of the water contained in the blast;
4. The decomposition of the carbonate of lime contained in the charges;
5. The reduction of the oxide of iron by means of solid carbon.

1. In the first case the value is positive, that is to say, the consumed carbon develops for each kilogramme burnt 8000 calories; while in the three following cases, the values are negative, that is to say, we have to calculate how much heat is absorbed.

2. Carbonic acid, during its transformation into carbonic oxide, absorbs the same quantity of carbon as it already contains; it thus follows that this carbon must absorb as much heat for its gasification, as it develops if burnt directly to carbonic oxide, that is to say 2400 calories. Thus the 8000 calories, which the first unit of weight of carbon developed, will, therefore, by the absorption of the second unit of weight, be diminished by 2400 calories, that is to say $8000 - 2400 = 5600$ calories.

3. The air blown into the blast-furnace is always mixed with a small quantity of aqueous vapour, and each unit of weight of the vapour, as it is transformed by the action of the burning carbon into carbonic oxide and hydrogen, absorbs as much heat as the 0.111111 hydrogen, which is produced by its decomposition, would have developed by its combustion, that is to say $34000 \times 0.111111 = 3778$ calories.

4. It is the same with the carbonate of lime, which is mixed with the charges. One unit of weight of carbonate of lime is composed of 0.56 lime and 0.44 carbonic acid; and the elimination of carbonic acid by means of heat will, therefore, produce an absorption of heat equal to $0.56 \times 197.1 = 110.376$ calories per unit of weight of carbonate of lime = 251 calories per unit of weight of carbonic acid.

5. If ores, incompletely reduced, attain a temperature at which the protoxide of iron is dissolved in the slag and begins to run, a pasty mass surrounds the pieces of fuel, and the protoxide of iron contained in that mass is then reduced by means of solid carbon, which is transformed into carbonic oxide. One unit of weight of protoxide of iron contains 0.2222 of oxygen; therefore, 0.387639 unit of carbonic oxide, containing 0.166131 unit of carbon, are produced by its reduction; and the quantity of heat thus absorbed is consequently equal to $0.166131 \times 2400 = 398.7$ calories. This last factor is one which plays a most important part in the action of a blast-furnace, as has been pointed out by Ebelmen, but it has been almost or entirely neglected by other metallurgists.

CHAPTER XIII.

CHEMICAL DECOMPOSITIONS EFFECTED BY HIGH TEMPERATURES.

It has long been a known fact that high temperatures are the cause of certain chemical decompositions; but it is only lately that it has been proved by Sainte-Claire-Deville that even compounds, the elements of which have the greatest affinity for each other, will be decomposed if the temperature to which they are exposed is sufficiently high; for the latent heat is not only given back to the elements, but the different molecules or atoms are by their expansion brought beyond the radius of their mutual attracting powers. M. Deville has thus shown that water, as well as carbonic oxide and carbonic acid, can be decomposed into oxygen and hydrogen, and oxygen and carbon respectively. The reason why this property had not previously attracted the attention of experimenters is that the separated elements, if not suddenly cooled, but if allowed to attain a lower temperature gradually, again combine before they can be analyzed.

The decompositions of carbonic acid and carbonic oxide are those which, for our present purpose, have the greatest interest, for these are the only ones which take place in the blast-furnace; and I will, therefore, mention a few experiments which have been made by Caillietet with regard to these decompositions. Caillietet took a tube of copper bent to the shape of an U, and put through one of its branches another copper pipe $\frac{1}{2}$ millimètre in diameter, this latter pipe passing through the curved portion of the first tube, and projecting a very short distance from it. At one end the smaller tube was tightly soldered with tin to the larger tube, whilst the other end projected sufficiently far from the open branch of the latter tube to be connected with an aspirator by means of a tube of india-rubber. The empty branch of the U tube was connected with a reservoir of water in such a manner that cold water passed continually through it.

This apparatus was inserted for a depth of 20 centimètres into the hearth of a blast-furnace, through the aperture left for

fired with pit coals; the gases were taken off immediately from above the fire-grate, and the following analyses were obtained:

		III.	IV.
O	13.15	..	12.33
CO	3.31	..	2.10
CO ^a	1.04	..	4.20
N	82.50	..	81.37
	<hr/>	<hr/>	
	100		100

These analyses are not more correct than those given above (I. and II.), for they ought to have given 59.74 and 66.29 nitrogen instead of 82.50 and 81.37. They prove, however, the existence of free oxygen and carbon, the more so, as the tube, when taken from the furnace, was found to be covered entirely with fine soot, which no doubt was formed by the conversion of the gaseous carbon into a solid state through the sudden cooling.

In order to examine at a still lower temperature the degree of decomposition of the products of combustion, the U-shaped tube was placed at a distance of 15 mètres from the grate of a steam-boiler, where the temperature just melted antimony. (Melting-point of antimony = 581.8° C.)

The analyses showed:

	V.	VI.
Oxygen	8.00	7.30
Carbonic oxide	2.40	4.02
„ acid	7.12	7.72
Nitrogen	82.48	80.96
	<hr/>	<hr/>
	100.00	100.00

instead of 61.54
and 64.22.

In order to obtain a check upon these results, the gases were now drawn off from the same place, through a metallic pipe, without being cooled, in such a manner that the free elements could enter into combination during the slow cooling.

The results were :

				VII.
Oxygen	..	..	..	1.21
Carbonic oxide	..	..	..	1.42
Carbonic acid	..	..	..	15.02
Nitrogen	..	..	..	82.35 instead of 40.80.
				<hr/> 100.00
Experiments V. and VI.				Experiment VII. gave
gave on the average :				on the average :
O 7.65				1.21
C O 3.21 = 1.605 carbon.				1.42 = 0.71 carbon.
C O ² 7.42 = 3.710 „				15.02 = 7.51 „
<hr/> 5.315				<hr/> 8.22

And the carbon separated by sudden cooling amounted, therefore to

$$8.22 - 5.315 = 2.905.$$

I have not myself made experiments in this direction ; but in my experiments on reduction when carried out at high temperatures, I always observed, in that part of the iron tube through which the cold gases entered, a residue of carbon, in the shape of fine soot, weighing several grammes.

These facts completely explain the influence of temperature on the reduction of the carbonic acid to carbonic oxide, for without taking into consideration the absorption of the latent heat of the carbonic oxide, which must necessarily take place, the requisite surface of contact, as we have found, may really become equal to *nil*, if the temperature is high enough to transform the carbon into the gaseous state. It may thus be possible that at a sufficiently high temperature the carbon is transformed into the gaseous state in a greater proportion than that corresponding with the carbonic oxide. This circumstance would then justify the general opinion of metallurgists, that the higher the temperature in the hearth of a blast-furnace, the more advantageous are the results obtained, for it is true that a greater quantity of carbon would much accelerate the reduction of the ores.

It may further be stated, in favour of this opinion of metallurgists, that Ebelmen's analyses of the gases of blast-furnaces show everywhere an excess of carbon, which could not have been produced by the combustion of the gases with the blast: the circumstance also that this excess of carbon is accompanied by a corresponding excess of oxygen which cannot originate from the blast, would not be against this opinion, for this excess of oxygen comes from the reduction of the oxide of iron in the ores, and it must, therefore, be transformed into gas, as soon as the carbon vapour comes in contact with the oxide of iron. The wonderful, and until now unexplained, effect of the hot blast could also be explained in this manner, as the temperature, being increased by the hot blast, must evidently favour the vaporization of the carbon. However tempting this supposition may be, however, I feel convinced that it is not the case, and that for three reasons:

1. Even if we employ every means for increasing the temperature in the hearth of the furnace, as for instance, pressure of blast, preliminary heating of the blast, dry air, &c., &c., the reduction of the carbonic acid, or, we may say, the vaporization of the carbon, will absorb so much heat, directly above that point where the high temperature is produced by the formation of the carbonic acid, that the temperature will be reduced to almost half the original one; and the temperature actually obtained will therefore be even less high than it would have been without applying the means for increasing it. It can thus scarcely be admitted that the carbon remains in a gaseous state in any notable proportions, and the effect of these means for increasing the temperature is, therefore, reduced to a diminution of the zone or space in which the formation of the carbonic acid and its reduction, or the vaporization of the carbon, take place; of course, the acting capacity of the boshes is thus a little, but only a little, enlarged.

2. The preliminary heating of the blast may be used as a means for saving fuel, as well as to effect the complete reduction of the ores in a shorter time. The temperature is not increased in the first case, and the saving of fuel is proportionate to the

quantity of heat which was added to the blast by its preliminary heating. But if a hot blast be applied, without diminishing the quantity of fuel in proportion to the ores charged, the temperature will be increased not only in the hearth of the furnace, but in the whole shaft. The consequence is that the ores arrive more quickly at a zone the temperature of which is sufficiently high to cause the oxide of iron, which still exists together with the material forming the slags, to combine and form a pasty mixture; and the reduction of this oxide of iron can be then no longer effected, either by means of vaporized carbon or by means of carbonic oxide, but it can only be transformed into metallic iron by means of solid carbon, which is mixed with or surrounded by the pasty mass.

3. This reduction of the iron by means of solid carbon has, therefore, to be considered as an explanation of the effect of the increased temperature, which coincides much better with the facts of the case than the supposition that there is a vaporization of the carbon beyond the proportion due to the oxygen contained in the carbonic oxide.

This is the irrefutable explanation which M. Sainte-Claire-Deville's ingenious metallurgical experiments give of the process of cementation, an explanation which was for a long time searched for in vain, and this notwithstanding the great attention which it received.

If, as Cailletet's last experiments show, 2.905 per cent. of vaporized carbon can exist at a temperature of 581.8°C , it follows that the iron at the temperature of the cementing furnace is always exposed to an atmosphere which contains considerable quantities of free carbon in a vaporized state, and which can enter into combination with the iron.

CHAPTER XIV.

RESISTANCE OF THE COLUMN OF FUSION.

Not only in the shaft of the blast-furnace, but in any apparatus for combustion, the fuel offers to the entering air, and to the rising gases, a more or less considerable resistance; but an exact measurement or determination of this resistance is impossible because it (the resistance) is never constant, and depends chiefly upon the size of the pieces of fuel, the composition of the gases, and their temperature.

If, however, an exact determination is impossible, it is nevertheless desirable to find an approximate value for this resistance, for this alone will enable us to ascertain means by which it may be diminished.

I have, therefore, used the experiments on the surface of contact of the fuel (Chapter III.) for ascertaining the value and the degree of approximation of those coefficients and formulas which serve for the determination of this resistance.

The gases which rise between the pieces of fuel have to force their way through an infinite number of very small passages, which are formed by the different layers of the pieces of fuel; and we may, therefore, use the same coefficients which are applied for conducting air through a whole system of pipes; there being, however, this difficulty, that the irregularity of the channels is so great that it is impossible to give an exact value to their forms and dimensions.

If the pieces of fuel were balls of equal diameters, the form and size of these passages could be almost exactly calculated; and for want of a better base for our investigations we must accept this assumption, that the pieces of fuel are spheres of equal size.

The total area of the passages is thus equal to the area obtained by subtracting from the unit of surface (1 square mètre) that surface which is covered by the balls if placed horizontally side by side. 1110 balls of 0.03 mètre diameter will

cover the unit of surface of one square mètre; and the section of one of these balls is equal to

$$\frac{0.03^2 \cdot \pi}{4} = 0.00070686 \text{ square mètre,}$$

whence the total section of 1110 balls = $1110 \times 0.00070686 = 0.7846$ square mètre,* and the total area of the many small passages between the pieces of fuel is $1 - 0.7846 = 0.2154$ square mètre. This area remains the same, whatever the diameter of the balls may be, supposing always that they are uniform in size. The velocity per second with which the gases pass through, is obtained by dividing this free area between the balls by the volume of the gases at a corresponding temperature.

The resistance which is offered to the passing of the gases through the free area consists of

- a. The friction against the walls of the passages;
- b. The variation of the direction of the current of the gases round the isolated pieces.

A third factor, that is to say, the variation of the sections, producing expansion and contraction of the gases, should be added. But these values can only be insignificant; and I have, therefore, as the following calculation is only an approximate one, neglected this last factor altogether.

In order to bring a gas into movement, a force is required, which consists either of the pressure acting upon the blowing cylinder, or of a negative pressure or exhaustion produced by a chimney. This pressure can be represented by an equivalent column of mercury, water, or gas; any resistance produces a diminution of this column of pressure, and the resistance itself

* This should evidently be 0.7854 square mètre, or the area of a circle one mètre in diameter. The slight error in M. Schinz's calculation is caused by taking the approximate area of the small circle 0.03 mètre in diameter, and then multiplying this area by 1100. It follows that the gross sectional area of the spheres being 0.7854 square mètre, the area of the clear space between the latter will be $1 - 0.7854 = 0.2146$ square mètre, and not 0.2154 square mètre, as stated above. See also footnote to page 15.

may, therefore, be expressed and calculated as a column of pressure.

This column of pressure is not always known, but only the velocity with which the gases pass through the free spaces; the velocity depends, however, upon the column of pressure, and the latter may thus be obtained from the former, for

$$p = \frac{v^2}{2g}, \text{ or otherwise } v = \sqrt{2gp},$$

if p = column of pressure, v = velocity, and g = 9.81 mètres.

In order to determine at first the temperature and the volume of the gases, and thus subsequently ascertain their velocity, we are obliged to refer to the analysis of the gases. The study of the resistance upon the hearth has been made by means of the experiments described in Chapter III., and we find there the results of all the analyses.

We shall now show by an example how these analyses have to be applied for our present purpose; and we shall take, for instance, the experiment No. VI., which gave: 1.2567 cubic mètre of carbonic acid, containing 0.62835 cubic mètre of carbon vapour; next, 0.033477 cubic mètre of carbonic oxide, containing 0.01673885 cubic mètre of carbon vapour; which give

$$\begin{array}{l} 0.62835 \times 1.07272 = 0.674040 \text{ kil.} \\ 0.01673885 \times 1.07272 = 0.017956 \text{ „} \end{array} \left. \vphantom{\begin{array}{l} 0.62835 \\ 0.01673885 \end{array}} \right\} \text{ of carbon.}$$

These quantities produced by their combustion

$$\begin{array}{l} 0.674040 \times 8000 = 5392.3 \text{ calories} \\ 0.017956 \times 2400 = 43.1 \text{ „} \end{array} \left. \vphantom{\begin{array}{l} 0.674040 \\ 0.017956 \end{array}} \right\} = 5435.4 \text{ calories,}$$

whence has to be deducted the latent heat of the steam contained in the gases, viz. $0.031408 \times 0.80475 = 0.025276 \text{ kil.} \times 536.67 = 13.5 \text{ calories}$; remainder, 5421.9 calories.

In order to calculate now the temperature on the hearth, the volumes of the gases, as obtained by the analyses, have to be transformed into weights, which again have to be multiplied by the specific heats of the gases; and the sum of these

products divided by the quantity of heat generated then gives the required temperature. We have

Cubic mètres.		Kils.	
5·0626	Nitrogen	= 6·3614	× 0·2440 = 1·5522
0·068891	Oxygen	= 0·089863	× 0·2182 = 0·019608
1·2567	Carbonic acid	= 2·4714	× 0·2164 = 0·534810
0·033477	Carbonic oxide	= 0·041896	× 0·2479 = 0·010385
0·0095647	Hydrogen	= 0·0008571	× 3·4046 = 0·002918
0·031408	Water vapour	= 0·0252760	× 0·4750 = 0·012006
<hr/> 6·4626407		<hr/> 8·9906921	
		<hr/> 2·131927	

The temperature existing on the hearth is thus equal to :

$$\frac{5421 \cdot 9}{2 \cdot 131927} = 2543^{\circ} \text{C.}$$

The volume of gas per hour at a temperature of $0^{\circ} \text{C.} = 6 \cdot 4626$ cubic mètres, equal at a temperature of 2543°C. to $66 \cdot 693$ cubic mètres, and of this quantity $\frac{66 \cdot 693}{3600} = 0 \cdot 01852$ cubicmètre passes

per second through the fuel. The area of the spaces between the pieces of coke during experiment No. VI. was $= 0 \cdot 009112$ square mètrè, and the velocity of the current was, therefore,

$$v = \frac{0 \cdot 01852}{0 \cdot 009112} = 2 \cdot 033 \text{ mètres per second.}$$

The column of pressure corresponding with that velocity and expressed in a column of the products of combustion is

$$p = \frac{v^2}{2g} = \frac{2 \cdot 033^2}{19 \cdot 62} = 0 \cdot 2108 \text{ mètrè.}$$

I have calculated in this way the temperatures and columns of pressures for the first nine experiments, and the results are as follows :

Experiment No.	I.	II.	III.	IV.	V.
Temperature	1047°	1758°	2709°	1501°	2048°
$p =$	0·2085	0·6526	0·4825	0·4810	0·3985
Experiment No.	VI.	VII.	VIII.	IX.	
Temperature	2543°	1398°	2706°	1824°	
$p =$	0·2108	0·4113	0·29467	0·05049	

The ascensional power of the gases in the chimney was the

power which was at our disposal during our experiments, and this power, measured by a corresponding column of pressure, has now to be determined, in order that we may be able to afterwards compare with it the resistances, to which in reality it should of course be equal. As we have already stated, when describing the experiments in Chapter III., the temperatures of the gases entering the flue had to be determined for that purpose. The results are :

Experiments	I.	II.	III.	IV.	V.	VI.	VII.	VIII.	IX.
	173°	308°	318°	193°	255°	240°	132°	227°	339°

The power or column of pressure produced by the flue is

$$p = h - (h \cdot s \cdot y),$$

if p = the column of pressure produced, h the height of the flue in mètres, s the specific weight of the gases after their dilatation by the temperature existing in the chimney, and y the specific weight corresponding to the nature and composition of the gases.

This last value is obtained by dividing the volume of the gases by their weight; for example, the volume for experiment VI. is 6·4626 cubic mètres, and the weight = 8·9907 kils. = $\frac{8 \cdot 9907}{6 \cdot 4626} = 1 \cdot 3912$ kil. per 1 cubic mètre; the specific weight is then $\frac{1 \cdot 3912}{1 \cdot 29366} = 1 \cdot 0754 = y$.

The value of s is obtained in a similar manner. The height of the chimney for these experiments was 10 mètres; and the following are now the values of s , y , and p , for the experiments I.-IX.

I.	II.	III.	IV.	V.
$s = 0 \cdot 61198$	$0 \cdot 46974$	$0 \cdot 4618$	$0 \cdot 58571$	$0 \cdot 5169$
$y = 1 \cdot 0245$	$1 \cdot 0492$	$1 \cdot 0862$	$1 \cdot 0383$	$1 \cdot 0612$
$p = 3 \cdot 7304$	$5 \cdot 0711$	$4 \cdot 9839$	$3 \cdot 9188$	$4 \cdot 5147$
VI.	VII.	VIII.	IX.	
$s = 0 \cdot 53202$	$0 \cdot 67395$	$0 \cdot 54586$	$0 \cdot 5169$	
$y = 1 \cdot 0754$	$1 \cdot 0378$	$1 \cdot 0581$	$1 \cdot 00643$	
$p = 4 \cdot 2785$	$3 \cdot 0957$	$4 \cdot 2241$	$4 \cdot 7966$	

* The
0° C.-

in kils. of a cubic mètre of air at

The resistances which absorb the column of pressure produced by the chimney are

$$\text{the friction } \frac{K C F}{4 S} \cdot p = p',$$

$$\text{the alterations in the direction } x \cdot p = p'',$$

$$\text{and the friction in the chimney } \frac{K L}{D} \cdot p + 4 p + p = p''',$$

where K = coefficient of friction = 0.024; $C F$ = surface of friction, which in the present case is equal to the

Surfaces of contact	I.	II.	III.	IV.	V.
	0.1347	0.36444	0.71077	0.15715	0.42519 sq. mètre.
	VI.	VII.	VIII.	IX.	
	0.82924	0.23498	0.63576	1.2399	sq. mètre.

While S , the spaces between the pieces of coke, is equal to	I.	II.	III.	IV.
	0.0051725	0.007008	0.009112	0.0051725 sq. mètre.
	V.	VI.	VII.	VIII.
	0.007008	0.009112	0.0051725	0.007008 ..
	IX.			
	0.009112			sq. mètre.

The values of p for high temperatures have already been given; x represents the number of spheres, placed above each other on the hearth, according to which also the number of alterations of the direction of the current has to be determined.

The values of x are for

I.	II.	III.	IV.	V.	VI.	VII.	VIII.	IX.
1.771	3.543	5.314	2.066	4.133	6.200	3.100	6.200	9.300.

The value p for the chimney is obtained from the volume of the gases per second; it is for the experiment VI. at $0^\circ = \frac{6.4626 \text{ cubic mètres}}{3600} = 0.001795 \text{ cubic mètre per second, equal, at}$

240° , to $0.003374 \text{ cubic mètre}$. But the section of flue = $0.00465 \text{ square mètre}$, whence the velocity $v = \frac{0.003374}{0.00465} = 0.72565 \text{ mètre per second}$, and the column of pressure $p = \frac{0.72565^2}{19.62} = 0.02685$.

The series of values for the experiments are

I.	II.	III.	IV.	V.
0.07535	0.12145	0.07275	0.041047	0.04682
VI.	VII.	VIII.	IX.	
0.02685	0.05880	0.01884	0.01728.	

L is the height of the chimney = 10 mètres, and D its diameter = 0.077 mètre, whence the column of pressure consumed by friction and alterations of directions in the chimney for experiment VI. is equal to

$$\frac{0.024 \times 10}{0.077} \cdot 0.02685 + (4 \times 0.02685) + 0.02685 = 0.97117 = p''',$$

where $4p$ is the value for two rectangular bends, or alterations of direction, and p is the pressure corresponding to the velocity of efflux of the gases.

Substituting now all these values in the formulæ given above, we obtain the following final results :

Experiment No.	I.	II.	III.	IV.
Column of pressure produced by the chimney p	3.7304	5.0711	4.9839	3.9188
Resistance of friction between the pieces of coke p'	0.08315	0.20393	0.22582	0.08768
Resistance produced by the bends in the hearth p''	0.94609	2.31570	2.56410	0.99401
Resistance produced by the chimney itself p'''	2.67050	3.26790	2.41250	2.40500
Total resistance ..	3.69974	5.78753	5.20242	3.48669
Differences from $p -$	0.03066	+ 0.71643	+ 0.21852	- 0.43211

Experiment No.	V.	VI.	VII.	VIII.	IX.
p	4.5147	4.2785	3.0957	4.2241	4.7966
p'	0.14507	0.11510	0.11211	0.16039	0.041222
p''	2.17830	1.30700	1.25700	1.97970	0.469550
p'''	1.99240	0.79117	2.05650	1.59650	2.526900
Total resistance ..	4.31577	2.39327	3.42561	3.73659	3.037672
Differences from $p -$	0.19893	- 1.88523	+ 0.41991	- 0.48751	- 1.758928

These results show that the differences in six cases out of

nine are only very small, and are some negative and some positive, and that the formulæ and coefficients applied for these determinations of resistance therefore deserve confidence.

If we now apply these formulæ and coefficients to the blast-furnace and to the column of fusion, we are met by the difficulty that neither the fuel nor the ores nor the slags in the shaft of the furnace will be in particles of an uniform size; even if that should be the case when the furnace is charged, this uniformity will have disappeared in the boshes. We cannot know how large these pieces will be, and yet everything will depend upon that size; for the resistance is much greater in the lower part of the furnace than in the upper part of the shaft. But these inevitable difficulties do not greatly prejudice the value of the method given; for under similar circumstances, that is to say at equal temperatures and with pieces of the same size, the result will always remain the same; and the value of this method consists in the means which it offers for ascertaining how the resistance of the column of fusion can be modified. This subject is especially of the greatest importance in the investigation of the shape and dimensions of the blast-furnaces.

CHAPTER XV.

TRANSMISSION OF THE HEAT THROUGH THE WALLS OF THE FURNACE.

THE blast-furnace at Clairval, with which Ebelmen first undertook his investigation on the composition of the gases of the blast-furnace, consumed for each kil. of pig-iron 1.48 kil. of charcoal.

Before this number can be used for demonstrating the transmission by the walls, it is necessary to rectify it, for one unit of weight of this charcoal contains 8 per cent. of water, thus reducing the weight in a dry state to 1.3616 kil. This charcoal also loses by dry distillation 13 per cent., consisting of hydrogen, oxygen, and carbon, and which, therefore, do not take part in the combustion; and the 1.3616 kil. is thus further

reduced to 1·1846 kil. This charcoal contains finally 3 per cent. of ashes, amounting for the 1·3616 kil. of dry charcoal to 0·0485 kil. The consumption of pure carbon is thus equal to 1·1361 kil.

The work done by this 1·1361 kil. of carbon does not consist, however, of only melting 1 kil. of pig-iron; but besides, 1·682 kil. of materials, forming the slags, have to be melted, 0·338 kil. of carbonic acid has to be set free from the ores and limestone, and 0·177 kil. of water has to be transformed into steam. The preliminary heating of the carbon is not taken into account, because the combustion again sets free the heat absorbed.

	Calories.
1·000 kil. of pig-iron absorbs in melting, as latent heat =	175
In being raised to the temperature of 1175°, the melting-point, it absorbs $1:0\cdot134487::1175$ =	158
1·682 kil. of material for the slag absorbs as latent heat $1\cdot682 \times 60$ =	101
And for the preliminary heating to 1300°, $1\cdot682 \times 0\cdot171912 \times 1300$ =	376
0·338 kil. of carbonic acid corresponds with 0·768 kil. of carbonate of lime; and as the setting free of the carbonic acid requires as a substitution for the heat of combination 110 calories, we get $0\cdot768 \times 110$ =	84
0·177 kil. of water absorbs as latent heat during its evaporation $0\cdot177 \times 536\cdot67$ =	95
<hr/>	
In order to produce, therefore, one kil. of pig-iron, there is required	989
Half of the consumed carbon, = 0·56805 kil., produces by the formation of carbonic acid $0\cdot56805 \times 8000$ =	4544
The other half absorbs for its transformation into carbonic oxide $0\cdot56805 \times 2400$ =	1363
<hr/>	
And the actual production of heat, therefore, is	3181
Whilst the consumption is only	989

The difference, equal to 2192 calories, represents, therefore, almost 69 per cent.

When such a calculation of the loss of heat is seen for the first time, it seems almost incredible, and the reason for it will be sought without being found. I endeavoured for many years to determine the exact value of this transmission, which not only occurs in the blast-furnace but in all furnaces or stoves. I tried to make available for this calculation the loss of heat which takes place through the walls of our dwelling-houses, and this gave very useful results; when, however, I had improved my pyrometer so that it could be used for determining the temperature of a glass-furnace, I became convinced that the transmission could not be determined by any other method than that described above. As long as the effective temperature of the glass-furnace was unknown and could only be assumed, the formulæ for the transmission given by Dulong and Petit might be applied; but it was altogether different as soon as the temperature of the furnace was found to be much lower than had been previously supposed. In the face of these facts I was obliged to give an account of the causes of this insufficiency of Dulong's coefficients, which had been so often examined and confirmed. It is true that those coefficients of the transmission had been obtained by apparatus which did not prevent the circulation of the air; but an admission of fresh air was excluded. It might, therefore, be easily assumed that the free circulation of the air, especially at higher temperatures, must be the cause which increases considerably the actual transmission of the heat above that obtained by calculation. When I determined the temperature of the glass-furnace I found this augmentation to be tenfold, and it was difficult to understand why the circulation of the air, which was only produced by absorption of heat, should have such an effect; I tried, therefore, to explain this fact by experiments.

I constructed for that purpose the apparatus represented by Fig. 11. In the vessel A, made of zinc, and open at the top and closed at the bottom, are placed fifteen brass tubes *b b*, which, as shown by the figure, are connected with each other.

A cylindrical copper vessel C with the tube D, communicated with the system of pipes *bb* by means of the mouth-piece *e*. The vessel A is provided with a small pump F, which allows the water contained in A to be maintained in a state of active circulation. The vessel C is provided with a grate, underneath which is fastened a plate of thin sheet iron, which prevents the cinders from falling into the tubes D and *bb*. This vessel C served as hearth for the combustion, and the products of combustion were aspirated through D and *bb* into a gasometer of 100 litres capacity, by means of a caoutchouc pipe fastened to the mouth-piece G. The vessel C is provided during the operation with a cover, which is constructed in such a manner that the radiant heat from the hearth is caught by the cover, and used for the preliminary heating of the air necessary for the combustion; a loss of heat is thus prevented as much as possible. The temperature of the water in A, the temperature of the products of combustion escaping through G, and the temperature of the room in which the experiments were made, were also exactly determined.

The heat generated in the vessel C was

- a. Partly transmitted through the walls of the vessel and the tube D to the air;
- b. Partly absorbed by the water in A;
- c. Partly taken away by the products of combustion through G.

These latter quantities deducted from the heat effectively produced, gave the heat lost by the transmission. In order to know the quantity of heat effectively produced, the products of combustion drawn off were analyzed; and this analysis gave the proportions of C, CO, and CO², whence the heat produced could be calculated; for 1 cubic mètre of gaseous carbon transformed into CO² gives 8581 calories, and 1 cubic mètre of carbon transformed into CO gives 2574 calories.

The initial temperature of the fire in C could thus be ascertained, after the specific heat of the products of combustion had been determined.

The experiments Nos. I, II, and III., were made with the apparatus described above, but for experiments IV., V., and VI., a clay pipe of an inside diameter of 44 millimètres and outside diameter of 62 millimètres, and a length of 300 millimètres, was connected so as to be air-tight with the mouth-piece *e*, this pipe being substituted for the vessel C and the tube D. This clay pipe was also provided with a small grate, in order to support the fuel used (small pieces of charcoal).

The following results were obtained :—

Results of the Experiments.	I.	II.	III.	IV.	V.	VI.
Temperature of the water in A } before the experiment .. }	30°	33°	36·5°	21°	27°	30°
Temperature of the water in A } after the experiment .. }	31·5	35	38	23	29	32
Temperature of the air in the } laboratory }	21	21	21	23	23	23
Temperature of the products } of combustion at G }	30·6	37·6	40·4	21·8	26·6	30
Difference of the temperature } of the water }	1·5	2	1·5	2	2	2
Difference of the temperature } of the air and of the products } of combustion at G }	9·6	16·6	19·4	—1·2	3·6	7
Time occupied by the experi- } ments in minutes }	6	3	3·5	8	12	9

Composition of the Products of Combustion.		I.	II.	III.	IV.	V.	VI.
Volume of C O^2	.. .. .	0.1688	0.1312	0.2349	0.1373	0.1072	0.0468
" C O}	.. .. .	0.0320	0.0478	0.0346	0.2437	0.0209	0.0254
" O}	.. .. .	0.1265	0.1811	0.1398	0.0860	0.0412	0.0279
" N}	.. .. .	1.4824	1.2648	1.4747	1.2982	0.5976	0.3240
Total volume submitted to the analysis	.. .. .	1.8097	1.6249	1.8840	1.7652	0.7669	0.4241
Total quantity of the products in litres :							
C O^2	.. .. .	9.32	8.07	12.47	7.78	13.99	11.03
C O}	.. .. .	1.77	2.94	1.84	13.81	2.72	5.99
O}	.. .. .	6.99	11.15	7.42	4.87	5.37	6.58
N}	.. .. .	81.92	77.84	78.27	73.54	77.92	76.40
Quantity of carbon contained in C O^2 in litres	.. .. .	100	100	100	100	100	100
" " " C O}	.. .. .	4.66	4.035	6.235	3.89	6.995	5.515
Total quantity of carbon in litres	.. .. .	0.885	1.470	0.920	6.905	1.360	2.995
Heat produced :							
1000 litres = 1 cubic metre to 8581 calories	.. .. .	5.545	5.505	7.155	10.795	8.355	8.510
" " " 2574 "	.. .. .	42.9	37.1	57.4	35.8	64.4	50.7
Altogether for the time given above	.. .. .	2.3	3.8	2.3	17.8	3.5	7.7
Production of heat per hour (in calories)	.. .. .	45.2	40.9	59.7	53.6	67.9	58.4
	.. .. .	452	818	1023	402	339	389

The transmitting surface of the vessel C and the tube D is = 0.10366 square mètre, and that of the clay pipe = 0.0086 square mètre, whence it follows that the transmission per square mètre was :

I.	II.	III.	IV.	V.	VI.
3492	5547	8325	36628	32558	36046 calories.

Of course, the temperature of these transmitting surfaces could not be the same at all points, and the quantities transmitted correspond, therefore, with the average temperature of these surfaces.

What temperatures of the wall of the vessel correspond then with the effective transmissions shown? We find, if we examine the Table given in Chapter XXVI., that for the values of t' Q, which correspond with these numbers, we get 228°, 289°, 344°, 546°, 530°, and 544°. If these were the average temperatures of the surfaces of transmission, the latter must have had much higher temperatures on those parts where the fire was. But all bodies give a distinct light, that is to say they become red hot as soon as they acquire the temperature of 525° C., and such a state not having been perceptible in any way, it follows that the quantity of heat absorbed by transmission must have been much greater than that calculated according to Dulong's formula.

I found with a glass-furnace, the temperature of which was accurately measured in order to calculate the transmission exactly, that for a certain value $\frac{e}{C}$ (Chapter XXVI.), per square mètre and per hour, the transmission was = 3801 calories; the effective transmission, however, found by deducting the quantities of heat lost and absorbed from the quantity produced, gave = 44073 calories. The values of t for the theoretical and the effective transmission are 241° and 571°; and the proportion of these numbers is $\frac{571}{241} = 2.37$. The value $t = 241^\circ$ was found by

means of the formula $t' = \frac{T - t''}{1 + Q \frac{e}{C}} + t''$, in which the fraction

$\frac{e}{\bar{O}}$ has been taken into consideration; the latter will, therefore, be proportionate to the value $t' = 571^\circ$.

We will suppose, in order to calculate *a priori* the effective transmission, that the latter is proportionately equal to the higher temperature which the surface of the wall apparently acquires, in order to transmit the greater quantity of heat; and such a supposition is certainly at least approximately correct. The theoretical transmission can, therefore, be found from the effective transmission by dividing the value t' by 2.37 , and the effective transmission can on the other hand be found from the theoretical transmission by multiplying the theoretical value t' by 2.37 .

We obtain thus:—

	Theoretical Transmission.		Effective Transmission.		
	t' .	$t'Q = Tr$.	t' .	$t'Q = Tr'$.	$\frac{Tr'}{T}$.
	°	calories.	°	calories.	
For the glass-furnace ..	241	3801	571	44167	11.62
Experiment I.	96	891	228	3419	3.83
" II.	122	1244	289	5530	4.44
" III.	145	1604	344	8349	5.20
" IV.	230	3476	546	36704	10.56
" V.	223	3282	530	32612	9.93
" VI.	229	3400	544	36165	10.63

The laws of transmission were, therefore, correctly ascertained by Dulong's genius; and the transmission increases in a geometrical progression with the temperature of the outside wall.

In the blast-furnace for the production of pig-iron and with the present mode of working, a certain loss of heat by transmission is even necessary, as there would otherwise be found in the hearth a temperature of between 2700°C . and 3000°C ., which would be very destructive to the walls. It is different with the upper parts of the shaft, where a concentration of the heat must be favourable to the process of reduction. In practice the furnaces are built as if matters were the reverse of what has

just been stated, the walls of the working part being made as thick, and the walls of the upper part of the shaft as thin as possible, while the latter, moreover, are fully exposed to the influence of the weather. Of course, with a constant temperature of the surface of the walls of the furnace the augmentation of this surface is of the greatest influence; if, for example, the temperature of the surface of the upper walls of the shaft is 10° higher than the temperature of the air, the theoretical transmission, that is to say the transmission calculated according to Dulong's formula, is, per hour and per square mètre, about 57 calories, the actual transmission perhaps 570 calories; the consequence is that a blast-furnace which offers to each ton of the charge one square mètre of wall, transmits only half the quantity of heat that is transmitted by another blast-furnace with two square mètres of surface for the same charge.

MM. Gruner and Lan, in their *Etat présent de la métallurgie du fer en Angleterre* (Paris, Dunod, 1862), are therefore quite right, when they attribute the saving of fuel in the working of the blast-furnace during the last ten or twenty years more to the increase of the size of the furnaces than to any other cause; but the same authors are not less right if they also attribute to this augmentation the deterioration in the quality of the products, and if they further attribute the adherence of the ironmasters of Staffordshire to blast-furnaces of the old forms and dimensions not to their fear of altering these dimensions, but to their eager desire to maintain the good quality of their products.

But this saving is caused by the less transmission of large furnaces which renders the consumption of less carbon necessary for attaining the same temperature; this smaller quantity of carbon gives, however, also less carbonic oxide to the shaft, and the reduction of the ores is less perfect, whence direct by means of solid carbon takes place, the result being that the products will contain more silicon.

The practical result of these observations is that the temperatures which increase the temperature of the products should be avoided, but the temperature should be maintained in the upper part of the shaft.

not only by diminishing the transmission, but also by increasing the quantity of the heat and the richness of the reducing gases, so as to obtain a maximum of production without deteriorating its quality.

CHAPTER XVI.

HEAT-CONDUCTING POWERS OF DIFFERENT MATERIALS.

A DISTINCTION has always been made between good and bad conductors of heat; but it is only recently that Péclet has indicated a very ingenious and simple method of determining the exact coefficients of the conducting power of materials. These coefficients express the quantity of heat which any material allows to pass in the unit of time, unit of thickness, and unit of surface for the difference of 1° temperature between the heated and the transmitting surface.

A cubic mètre of limestone, for example, which is heated on one of its six surfaces in any way, but is exposed on the opposite side to the air, gives up on this latter surface, for a difference of 1° temperature between the two surfaces, 2.08 calories during the unit of time; but a corresponding cube of fir only transmits 0.093 calorie under similar circumstances. If this difference of temperature should amount to 10° , the heat transmitted per hour would in these two cases be equal to 20.8 and 0.93 calories respectively.

If C indicates the coefficient of the conducting power, Q the number of calories which, according to Dulong's formula, are transmitted in the temperature $t' - t''$ per hour and per square thickness of the conducting body; t the temperature of the heated surface; t' that of the outer or transmitting surface, and t'' the temperature of the air, we get

$$C = \frac{Q}{e(t' - t'')}.$$

The values of t and t'' are obtained by direct measurement during the experiments, as is also the value of e , the thickness of the material, while Q is found by calculation.

Fig. 12 represents a vertical section through the apparatus used in researches of this kind. A is a thermo-electric column, consisting of bars of bismuth and copper wires; B is a rectangular vessel of copper, filled with water, and occupying the whole width and height of the column A, the contents of this vessel B being capable of being heated to any temperature below 100° C., by means of the lamp N, while a thermometer dipped into the water is used for ascertaining this temperature. C represents the body of which the conducting power has to be determined. I used for my apparatus square pieces, with a side of 12 centimètres and a thickness varying between 2 and 7 centimètres. F is a hollow box made of sheet copper, the side towards e being almost entirely open, only a margin 1 centimètre wide being left. This margin is provided with a caoutchouc washer pressed steam-tight against C by means of the bolts ff . The box F is supplied with steam from the small boiler H, the condensed water escaping through the pipe i ; while k and k' are two slides which protect the thermo-electric pile A from the heat of C and B, until the temperatures have become constant. The surface d is painted the same colour as the water-tank B, so that both surfaces have exactly the same radiating power.

The piece C, which has to be examined, is allowed to remain for an hour in contact with the steam in F, until no further heating is likely to take place. The temperature of the side e of the piece C is then evidently $= 100^{\circ} = t$. When the surface d and the surface of the box B have the same temperature, the thermo-electric pile A will remain inactive; but as soon as one of these surfaces is heated more than the other, the needle of the galvanometer, which has not been shown in the figure, will immediately deviate. The water in B is then warmed to such an extent that the galvanometer returns to zero; and when this occurs the temperature of the surface of B is equal to that of d , and the only unknown value in the formula, namely t' , is thus determined. The
veys heat not only to the surface d ,

but also to the whole circumference between d and e , and a coefficient of correction has, therefore, to be introduced, which can be determined by ascertaining the conducting power of the same body in a more complicated manner.

It would lead us too far away from our aim if we explained and described to the reader all these details, and it may be sufficient to have indicated in a general manner the method employed for the determination of the conducting power. But the knowledge of the heat-conducting power of different materials has a twofold application for our object, for it shows to us not only the means of limiting the transmission of the heat, but also of examining how quickly the heat penetrates the pieces of the charge, as we shall see later.

According to Péclet's experiments, the conducting power (= C) for various substances is as follows:—

	Specific Gravity.	Value of C.
Coal drawn from gas retorts (this represents coke) ..	1·61	= 4·96
Limestone	2·37	= 1·70
Fir (fibres parallel to its length)	0·48	= 0·170
Oak	—	0·211
Wood, charcoal pulverized	0·41	= 0·81
Coke, pulverized	0·77	= 0·160
Wood ashes	0·45	= 0·06
According to my observation bricks vary from	—	0·2428
to	—	0·8705
Argillaceous bricks pierced as shown in Fig. 13..	—	0·408
Still air	—	0·024
Iron	—	28·000

It will be seen that the conducting power increases, if not exactly, very nearly, in proportion to the specific gravity; and the porosity of a body, therefore, very much diminishes its conducting power.

CHAPTER XVII.

ABSORPTION OF HEAT BY THE CHARGES.

WE have no other means of determining the volumes of the zones in the shaft of a blast-furnace than by the *assumption* that the charge acquires the temperature of the gases which pass through it as quickly as it sinks in the current of these gases. This means, however, could not be relied upon if it was nothing but an assumption, and we have therefore to show that this hypothesis is in reality a fact.

The time necessary for any body to acquire the temperature of the medium in which it is placed depends upon its heat-conducting power, its density, and its specific heat. If we designate the first by C , the second by d , and the specific heat by s , we get the relation $K = \frac{C}{s d}$.

For iron ores of the least density, that is to say for spathic ironstone, $d = 3.6$; for limestone $d = 2.25$; and for coke 0.76 . The conducting power of the ores is not known; but if $d = 3.6$, C cannot be less than $= 5$. For limestone and coke C has the values 1.7 and 3 as minima; and we may take the maximum values of s for ores, limestone, and coke as equal to 0.2 , 0.3 , and 0.2 . We get then:

$$\text{for ores} \quad \dots \quad \frac{5}{0.2 \times 3.6} = K = 7;$$

$$\text{for limestone} \quad \dots \quad \frac{1.7}{0.3 \times 2.25} = K = 2.5;$$

$$\text{for coke} \quad \dots \quad \frac{3}{0.2 \times 0.76} = K = 20.$$

Now if an infinitely elastic body is in contact at one end with a constant source of heat of the temperature t , its temperature at a distance x after the application of the heat for t $- A$); and

$$A = \frac{e}{\sqrt{k\pi z}} \cdot \left[1 - \frac{\phi^2}{1 \times 3} + \frac{\phi^4}{1 \times 2 \times 5} + \frac{\phi^6}{1 \times 2 \times 5 \times 7} \dots \right]$$

$$\text{and } \phi = \frac{e}{2\sqrt{kz}}.$$

The charge of a blast-furnace is, however, not an indefinitely elastic body, but, on the contrary, is a body having but very slight elasticity; but the formula is nevertheless applicable, if we determine the value of e in another manner. Considering the different pieces of the charge as spheres, the surface which absorbs the heat is then the surface of the sphere itself, but the mass becomes smaller in departing from this surface. The volume of a sphere 0.06 mètre in diameter is 0.0001131 cubic mètre, and its surface = 0.01131 square mètre, whence the distance $e = \frac{0.0001131}{0.01131} = 0.01$ mètre. Coke has the greatest value for k , and it is, therefore, sufficient to show that pieces of coke of 0.06 mètre diameter after the time of one minute or 0.01666 . . . hours acquire the temperature of the surrounding gases. According to notations given previously, we have:

$$\phi = \frac{0.01}{2\sqrt{20 \times 0.01666}} = 0.00866$$

$$\frac{\phi^2}{1 \times 3} = 0.000025 \text{ and } \frac{\phi^4}{1 \times 2 \times 5} = 0.00000000056,$$

the sum of the two = 0.00002500056 and the remainder, if this quantity is subtracted from 1, = 0.99997,

$$\text{or } A = \frac{0.01}{\sqrt{20 \times \pi \times z}} \times 0.99997 = 0.99997.$$

If a ball of coke 6 centimètres in diameter is, therefore, exposed to gases at a temperature of $2000^\circ = t$, it would acquire after a minute the temperature

$$t' = t(1 - A) = 2000 \times 0.99997 = 1999.9^\circ.$$

This formula supposes, however, that the source of heat pro-

duces as much heat as the body absorbs, which is not always the case with reverberatory furnaces, but which no doubt is correct with respect to the blast-furnace, as the gases have still a temperature of at least 100° C. when leaving the throat of the furnace.

CHAPTER XVIII.

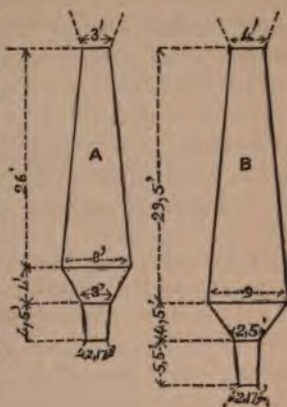
MEANS OF DIMINISHING THE TRANSMISSION OF HEAT.

THE first and best means of diminishing the transmission of heat from a furnace consists, as we have already stated, in obtaining the best possible proportion between total capacity and surface of walls. A furnace, for example, having a base 1 mètre square, and a height of 3 mètres, would have a capacity of 3 cubic mètres, and its walls would have a surface of 12 square mètres; the proportion is thus $3 : 12 = 1 : 4$. But a square furnace, with sides measuring 2 mètres and a height of 3 mètres, would have a capacity of 12 cubic mètres and a surface of walls equal to 24 square mètres, whence the proportion would be $12 : 24 = 1 : 2$. The latter furnace would, therefore, transmit at the same temperature and other equal circumstances only half of the heat lost in the first-mentioned furnace by transmission, and in this case half of the fuel could be saved which is required in the other furnace for supplying the heat transmitted; or, with equal consumption of fuel, a higher temperature could be produced in the larger furnace.

Scheerer, in his 'Treatise on Metallurgy,' vol. ii., p. 130, gives as an example of the influence of different constructions of furnaces upon the relative consumption of fuel, the dimensions of two blast-furnaces for coke at Neunkirch, which are represented by the annexed figures.

The furnace A has a capacity of 733·5 cubic feet, whilst the surface of its walls amounts to 554·85 square feet; the capacity of the furnace B, on the other hand, is 1117·03 cubic feet, and the surface of its walls 723·20 square feet, whence the pro-

portions: for A = 1:0.75, for B = 1:0.64. The cause of the smaller consumption of the furnace B is, therefore, not its different construction, but the difference in the size, and consequently the proportion between capacity and surface of walls. The same author compares at some length the coke blast-furnaces at Königshütte, in Upper Silesia, with those in Belgium, and explains the causes which make the relative consumption of fuel at Königshütte 2.45, whilst the consumption in Belgium is only 2.20; but in doing this he neglects the most important point, *viz.* that the capacity of the furnaces at Königshütte is only 1950 cubic feet, whilst that of the furnaces in Belgium



amounts to 3690 cubic feet. The proportion $\frac{3690}{1950} = 1:1.89$

would justify the much larger consumption of the furnaces at Königshütte in comparison with those in Belgium, and—instead, as we may say, of having to apologize to the directors of Königshütte for the unfavourable result obtained by his comparison of their furnaces—he could have paid them a well-deserved compliment. We have so far only taken into consideration the inner surface of the walls, which in fact is that which absorbs the heat in the first place; but the amount of heat transmitted can be considerably modified by the greater or less thickness of the walls, and by the degree of heat-conducting power possessed by the casing of the inner walls. Thus there results the formula:

$$t' = \frac{t = t''}{1 + Q \frac{e}{C}} + t'',$$

where t' = the temperature of the outer surface of the walls;

t'' = the temperature of the atmospheric air; t = that of the air inside the furnace; e = the thickness of the wall; Q = the transmission which takes place per square mètre and per hour at the temperature t' , expressed in centigrade degrees; and, finally, C = the conducting power of the material of which the wall of the furnace consists.

The following Table by Péclet gives the quantity of heat transmitted by each mètre in length, of a horizontal tube of 0.1 mètre diameter inside, and heated by steam to 100° C., the surrounding air being calm, and being kept at the temperature of 15°. The results in the Table are given for different thicknesses of tube, and for various values of the conducting power of its material = C :

		Thickness of Sides of Tube = e .						
		Mètres. 0.01	Mètres. 0.02	Mètres. 0.03	Mètres. 0.04	Mètres. 0.05	Mètres. 0.10	Mètres. 0.15
		Heat Transmitted.						
Value of C	0.04	74.6	50.2	39.1	32.3	28.2	18.7	15.0
	0.08	109.2	82.7	67.8	58.3	51.8	34.1	29.4
	0.16	142.1	122.1	107.9	97.3	89.4	63.4	56.6
	0.32	167.3	160.4	153.1	146.3	140.2	111.3	103.2
	0.64	183.6	190.2	193.8	195.2	196.0	178.6	177.3
	1.28	193.3	209.7	223.4	234.5	244.6	256.1	276.7
	2.56	198.0	221.0	241.9	260.8	279.2	327.0	384.6
	5.12	200.7	227.1	252.3	276.3	300.4	379.6	477.6

This comparison shows clearly the influence of thickness and conducting power of the walls. It shows that the transmission decreases very quickly as the thickness of the walls increases, if the conducting power is small; but the thickness of the wall exercises but little influence, as soon as the conducting power augments to 0.64, and if the latter increases, the augmentation of the thickness of the walls becomes very disadvantageous. The least transmission, therefore, takes place when the conducting power of the material is as small as possible, and the thickness of the walls as great as possible.

Of course, certain limits must be kept with respect to the last condition, or the interest of the additional expenses incurred will not be any longer in proportion to the saving of fuel which might be obtained. The conducting power, however, can be considerably reduced without any additional expense :

- a. By the choice of the material ;
- b. By cavities ;
- c. By adding to the outer surface a last layer, the radiating power of which is smaller than that of the material forming the wall.

I have often found that the conducting power of bricks from the same kiln, when forming a wall which is exposed to hot gases, differs very much with the different bricks ; some of these bricks are so hot that they cannot be touched without burning the fingers, whilst others, in their immediate neighbourhood, are almost cold. These great differences can only originate from the different temperatures in the kiln, by means of which some of the bricks have been burnt more and others less ; the latter thus possessing, on account of their inferior density, inferior heat-conducting power.

The walls of blast-furnaces, however, have to be distinguished with respect to the conditions which the inner shaft and the outside masonry have to fulfil. Porous bricks of less density, if used for the inner shaft, would lead to a quicker destruction of the latter by fusion and other mechanical actions, than hard and compact bricks, and it is in the outside casing alone, therefore, that the use of a material of less conducting power is admissible.

The minimum conducting power, given in Chapter XVI. for burnt bricks ($= 0.2428$), refers to bricks which had been made porous to such a degree—by means of a very large addition of powdered charcoal—that they would swim in water. Such bricks could be used for the outside masonry, for they resist the pressure well enough, but they must not be exposed to moisture, because they are easily disintegrated by the air. Hard-burnt hollow bricks, the conducting power of which has been found to be $= 0.2449$, would, however, resist the weather.

But the transmission can still be reduced considerably by leaving hollow spaces inside the masonry; the enclosed air, being an exceedingly bad conductor of heat, producing a great effect, as it does in the hollow bricks.

The transmission of walls, formed of several layers of different conducting power, is calculated according to the formula :

$$t' = \frac{t - t''}{1 + Q \left(\frac{e}{C} + \frac{e'}{C'} + \frac{e''}{C''} \dots \right)} + t''.$$

For example :

For the inner wall $e = 0.25$ mètre and $C = 0.4200$

For the space between the inner and

outer wall filled with ashes of wood $e' = 0.15$ „ $C' = 0.0600$

For the inner layer of the outer wall $e'' = 0.20$ „ $C'' = 0.2449$

For the part filled with air $e''' = 0.15$ „ $C''' = 0.024$

For the outside layer of the outer wall $e'''' = 0.40$ mètre and $C'''' = 0.2449$

If we suppose $t = 1400^\circ$ and $t'' = 15^\circ$, we get, if $Q = 1$

$$t' = \frac{1400 - 15}{1 + 1 \left(\frac{0.25}{0.42} + \frac{0.15}{0.06} + \frac{0.2}{0.2449} + \frac{0.15}{0.024} + \frac{0.4}{0.2449} \right)} + 15 = 93^\circ,$$

whilst a wall of 1.15 mètre thickness, the conducting power of which = 0.42, will give :

$$t' = \frac{1400 - 15}{1 + 1 \left(\frac{0.42}{1.15} \right)} + 15 = 1001^\circ.$$

The coefficient of radiation of bricks is 3.62; if, therefore, with this coefficient, and with $t' = 100^\circ$, one square mètre radiates 562 calories per hour, the radiation would amount for the coefficients

= 0.13 for polished silver, only to 20 calories

= 0.258 „ brass „ 40 „

= 0.16 for copper „ 25 „

The only difficulty would be to keep such metallic covers of the outside masonry clean and bright; however, this expense would still be less than the saving that would be realized.

CHAPTER XIX.

THE REDUCTOMETER.

THE quantity of heat which a given weight of cast iron requires for its fusion, and the temperature of that fusion (1100° and 1250° C.), is, as known, very small when compared with the quantity of heat obtained from the carbon, which, according to experience, is necessary in the blast-furnace for the production of a given weight of pig-iron.

This greater quantity of heat is at least partly necessitated by the slag which accompanies the given weight of pig-iron. But the quantity of this slag is not the same for all ores; it varies with the nature of the latter, not only because different ores themselves contain different quantities of materials which form the slag, but also because different ores require different quantities of additional substances, which cause the quantity of slag to be augmented.

For the fusion of a given weight of slag more heat is required than for the fusion of the same weight of pig-iron, and the consumption of coal required for the production of a given quantity of pig-iron will, therefore, increase in a greater proportion than that for the quantity of slag by which this quantity of iron is accompanied.

The augmentation of the materials forming the slags, however, is by no means arbitrary, but it depends upon the time necessary for the ores to pass from the throat of the furnace through the shaft into that zone in which the pig-iron and slag become melted; this time, again, depending upon the greater or less reductibility of the ores. Only a certain number of charges can be contained in the blast-furnace, and the oxide in the ores will, therefore, remain longer exposed to the rising current of the reducing gases, according as this oxide is mixed with more slag-forming material. In practice, the correct quantity of slag-forming material is obtained by experience, as also the corresponding quantity of fuel; but this experience does not fix the

conditions under which the ores are reduced, nor the laws upon which this reduction is based.

I have considered it a very important problem to ascertain these laws, and I have spent years of labour in order to acquire this knowledge as exactly as possible. These laws refer to the influence of temperature, of the quality of the gases, of the quantity of the gases, of time, and of the quality of the ores.

With the exception of those made by Ebelmen on the blast-furnace itself, all experiments undertaken to ascertain the reductibility of ores have been made with pure carbonic oxide gas. I also at first went on in the same way, but I very soon found that the application of this gas scarcely allowed any differences to be perceived for different ores. I was then convinced that correct and useful results could only be obtained, if such gases were applied as are really to be found in the blast-furnace.

The composition of the gases found in the working part of the blast-furnace is almost constant, and is only a little modified by the blast being more or less damp; the problem, then, of producing real blast-furnace gases seemed to be very easy. I found myself, however, in that respect very much deceived. I tried different methods for the production of these gases, but could not obtain any constant result, and I was finally obliged to make at first other investigations, in order to ascertain the laws under which carbonic oxide gas is constantly formed, without a mixture of carbonic acid. It was these researches which led to the determination of the laws relative to the action of the surface of contact; but they did not prove sufficient for the production of a constant supply of carbonic oxide without carbonic acid, and a great number of further experiments had to be undertaken in order to determine the great influence of the temperature (see Chapter IV.).

Having ascertained in this manner that sufficient surface of contact and a high temperature are necessary for the formation of carbonic oxide, I concluded that the method employed in the blast-furnace itself is in every way the surest and cheapest.

I took, therefore, a cylinder of sheet iron, which had a height of 0.51 mètre and a diameter of 0.3 mètre, and built in it, with

refractory clay, a small blast-furnace, the capacity of which was 0.0111 cubic mètre.

Considering the pieces of charcoal which had to be used as spheres 0.15 mètre in diameter, one cubic mètre of such balls gives a surface of contact of 21 square mètres, whence the surface exposed by the charcoal in the furnace was $21 \times 0.0111 = 0.2331$ square mètre. At a temperature of 800° also, one cubic mètre of air per second requires a surface of contact of 1000 square mètres, and it was therefore necessary to introduce into the miniature blast-furnace 0.0002331 cubic mètre of air ($1000:0.2331::1:x$) per second.

The glass receiver, in which the gas was accumulated, contained 100 litres = 0.1 cubic mètre, and there was required, therefore, in order to fill this receiver, $\frac{0.1}{0.0002331} = 429$ seconds, or a little more than 7 minutes.

Fig. 14, Plate III., represents the whole apparatus. In this figure A represents the small blast-furnace, which communicates with the blowing apparatus BB by means of the tube *a*. The gases which the blast from BB produces in A pass through the cooling apparatus C, and thence into the glass receiver D of 100 litres capacity. In order to destroy the last traces of carbonic acid, the gases are conducted from D through the epurator E, the perforated bottom of which is covered with lumps of caustic lime, this lime at the same time drying the gases. From E they pass into the actual reducing apparatus FF, which is placed in the furnace GG. This furnace also communicates with the blowing apparatus BB, so that the fire can easily be kept in an active state.

The apparatus FF, for effecting the reduction of the ores, is represented in detail, and $\frac{1}{2}$ of the natural size, by Fig. 15. The gas is led, by means of a caoutchouc pipe, from E through the cock *a*; and the copper pipe *bb* is fastened air-tight in the wrought-iron tube *cc*, in which the tube *dd*, made of sheet iron, is placed as shown. The other end of this tube *dd* is fixed to the strong wrought-iron pipe *ee*, which terminates in the brass tube *ff* and the cock *g*.

The thermo-electric element *h h* forms, with the apparatus for measuring the current (not represented in the figure) the pyrometer. This element consists of the wrought-iron tube *i i*, to which is screwed a copper pipe *K K*; the platina wire *l l* being welded to one end of the iron tube and passing through its entire length. The space between the tube *i i* and the wire *l l* is filled with caustic lime, and the wire is insulated in the copper pipe *K K* by means of a glass pipe.

The thermo-electric element passes, as shown by the figure, exactly into the centre of the tube *d d*, in which the ores, which have to be experimented upon, are confined; and it therefore indicates exactly the average temperature to which the ores in this tube are exposed. Both ends of the tube *d d* are provided with perforated plates *m* and *n*, which prevent the ores from falling into the tubes *e e* and *c c*. Finally, the tubes *c c*, *d d*, and *e e* are placed together into a muffle of refractory material, both ends of this muffle being stopped each time with clay.

It is necessary that the glass bell *D* must sink uniformly from beginning to end of each experiment, that is to say, equal quantities of gas must enter the reducing apparatus during equal parts of time, and the glass bell is balanced for that purpose by means of the lever *v v* and the weight *w*.

The dial-plate *H* provided with a pointer serves to multiply the small movement of the bell, for the wheel *Z* which moves the pointer is fixed upon the same axis as the pulley over which the cord carrying the counter-weight *x*, runs. The bell *D* sinks more or less quickly, according as the cock *s*, which is placed above the epurator *E*, is opened more or less widely. Experiments have shown how many seconds are required for the advance of the pointer upon *H* by the distance of one degree if the bell sinks in 2, 3, 4, or 5 hours; and it is therefore possible by means of a watch showing the seconds, and the cock *s*, to regulate at the beginning of each operation, the time in which the bell shall pass 100 litres of gas into the apparatus.

In order to fill the bell *D* with gas, the cover over the furnace *A* is removed, the whole contents of charcoal completely heated, and after the cover has been again replaced, the communication with *D* is effected by sinking the cock *t*. This

preliminary operation is decidedly necessary, and requires even great precaution, as otherwise the gases are mixed with much carbonic acid.

The cocks *a* and *g* of the apparatus of reduction *FF* were intended to cut off gas and air from the ores in *dd* when an experiment had terminated; but this arrangement, however, did not answer. The ores already reduced were always again oxidized to some small extent by air which entered somewhere, and it was found that the only plan which could be adopted was to cool the ores in an uninterrupted current of gas, before the air was allowed to enter.

In Fig. 14, *T* is a cooling vessel filled with water, through which the thermo-electric element passes in such a manner that the copper pipe *kk* and the tube *ii* each occupy half of the length of this vessel. The temperature of the cooling vessel was determined at each observation by means of the thermometer *y*.

The length of the tube of reduction, *dd*, Fig. 15, is exactly 0.1 mètre between the perforated plates *mm* and *nn*, and the inside diameter is 0.047 mètre, whence the capacity of the tube, after deducting the space occupied by the projecting thermo-electric element, is equal to 110 cubic centimètres; this space was always filled with the ores to be examined. I tried at first, by using several perforated bottoms or discs, to place a series of different ores one after the other in the tube *dd*; but I soon found that the ore first met by the current of the gas was always the soonest reduced.

This circumstance, however, also causes some trouble, when only one ore is used in the experiment, for the last pieces touched by the gases are less reduced than those with which the current comes first into contact. If the state of reduction of the ores has, therefore, to be ascertained by means of a chemical analysis, it has to be observed that the same quantity is taken from the two ends of the tube *dd*, or that the sample is obtained only from the middle of the latter. All ores examined, artificial as well as natural, were made into uniform pieces, or into spheres of about half a centimètre diameter.

The result of each trial, that is to say, the quantity of the reduced oxide in the ores, could be best determined by weighing

the ores before and after the experiment; but this is unfortunately impossible, because the pulling down of the apparatus requires often such a power that the whole construction is shaken, and this often causes a partial loss of the contents; and besides, the pieces of ore are often stuck to the walls of the tube of reduction, and this prevents their being got out. Finally, the pieces of the ores themselves are not always of the same composition, and the determination of the results by means of analysis is, therefore, the best method for ascertaining how much oxygen has been lost by the ore submitted to the experiment.

For these analytical determinations I have used the following methods: If a piece of the ores put into diluted hydrochloric acid did not disengage any hydrogen, I pulverized 2 or 3 grammes of the mineral, and weighed about one-half of the quantity in a small flask and the other half in a flask with a long neck containing about $\frac{3}{8}$ of a litre.

The first quantity being exactly weighed, served for determining the whole quantity of iron in the ore. For that purpose pure hydrochloric acid was poured upon the powder, and the mixture was allowed to digest for a few hours in a bath of water at a temperature of 60° or 70° C. When all the powder was visibly decomposed, the whole was boiled over a spirit-lamp, and small pieces of chlorate of potash were then successively added, until the chlorine gas developed could be smelt. The fluid was then kept boiling, until the smell of the chlorine was no longer sensible even after a small addition of hydrochloric acid. The contents of the matrass were then put into a long-necked flask containing $\frac{3}{8}$ litre (Fig. 16), where they were diluted with about $\frac{1}{4}$ litre of distilled water. A spirit-lamp was then placed under the flask, and the mixture boiled during $\frac{1}{4}$ of an hour, in order to free the added water from all air, and the chloride of iron from all free chlorine.

A thin plate of copper, 9 centimètres long, $1\frac{1}{2}$ centimètre wide, and 1 or 2 millimètres thick, prepared by the electrotyping process and exactly weighed, was next fastened to a very long but very thin platina wire, and slowly dipped into the boiling fluid; and the flask was then closed by a cork which was provided with a hole into which a glass tube 40 centimètres long, 5 millimètres

in diameter, and with both ends open, was put in such a manner, that it projected for its entire length beyond the neck of the flask. This tube served to carry away the steam, for the contents of the flask were now kept uninterruptedly boiling, until they had become colourless, or of only a slightly greenish tinge: this boiling does not often require to be continued more than $\frac{3}{4}$ of an hour if the proportion of iron is small; but with ore containing a larger percentage of iron, the boiling must be continued for several hours.

The thin copper plate with the platina wire was next taken out of the flask, and washed by quickly dipping it into hot distilled water, and afterwards carefully dried. The plate was then again weighed, and the difference between the former and the present weight showed how much copper had been necessary in order to transform $\text{Fe}^2 \text{Cl}^2 + \text{Cu}$ into $2 \text{Fe Cl} + \text{Cu Cl}$. One gramme of dissolved copper corresponds with 0.88606 gramme of iron existing in the ore examined.

Next, the second portion of the ore weighed in a flask was mixed with the same volume of bi-carbonate of soda, and the flask (Fig. 17) then closed by means of a cork which was provided with two holes. A tube with a funnel was passed through one of the holes, whilst the second served for the reception of another tube, which was bent twice, and the free end of which dipped a few millimètres into water.

The flask was next placed on a small hot-water bath, and hydrochloric acid was introduced drop by drop through the funnel. Carbonic acid, which soon filled the flask, was thus quickly generated, a little more hydrochloric acid being added than the complete decomposition of the ore required. After this decomposition, which takes place in about half an hour, had been effected, $\frac{1}{2}$ of a litre of distilled water, which had been kept boiling for a quarter of an hour, was added.

A spirit-lamp was then quickly substituted for the hot-water bath; and when the contents of the flask began to boil, a thin piece of copper, as in the first part of the determination, was put into the vessel, which was afterwards again closed.

The protoxide of iron contained in the ores could not be oxidized, because it did not come in contact with the oxygen of

the air, and the loss of the weight of the thin piece of copper was consequently less, for it corresponded only with the existing contents of oxide of iron. These two operations served, in the following manner, for determining how much oxygen the partly-reduced ore had lost.

Let us suppose the quantity of ore used for determining the total contents of iron to be 1.345 gramme, and the loss in the weight of the copper 0.171 gramme, then the latter quantity will correspond with 0.15151626 gramme of iron = 11.272 per cent. of the ore.

Let us again suppose the quantity of ore used for determining the contents of oxide of iron to be 1.501 gramme, and the loss in the weight of the copper 0.156 gramme, the latter quantity will then correspond with 0.13822536 gramme of iron = 9.209 per cent. of the ore.

We have, therefore :

Total contents of iron 11.272

which contains as oxide $9.209 = \text{Fe}^2 \text{O}^3 = 13.1498$

$2.063 = \text{Fe O} = 2.6515$

The ore contains thus 15.8013 per cent. of oxide, which contain $15.8013 - 11.272 = 4.5293$ oxygen = 28.6641 per cent., and if the raw ore contains only $\text{Fe}^2 \text{O}^3$, the quantity of oxygen separated through reduction is for 100 oxide = $30 - 28.6641 = 1.3359$.

If the ore, however, when brought into contact with hydrochloric acid shows a distinct generation of hydrogen, a part of the oxide in the ore is already reduced to metallic iron, and the analysis has then to be conducted in a different manner, as follows:

Five grammes of the pieces of ore are coarsely powdered and put into a flask *a* (Fig. 18), of 30 cubic centimètres capacity; a cork, carrying two tubes, one a funnel and the other bent as shown, is used for closing this flask. A caoutchouc tube is fastened to one end of the bent tube and serves as a communication with the apparatus *c* filled with hydrate of potash (in pieces); while a second caoutchouc tube connects the apparatus *c* with the combustion tube *b b* filled with oxide of copper and communicating with a third apparatus *d* containing chloride of calcium, the

weight of which is exactly ascertained before the operation begins. Hydrochloric acid mixed with its half volume of water is gradually introduced through the funnel-tube, and the metallic iron is thus dissolved, and hydrogen generated. This hydrogen, in passing through the apparatus filled with hydrate of potash, loses all the hydrochloric acid and moisture which it contains, and pure hydrogen enters the combustion tube *bb*, where it is transformed by combustion into water, which is collected in the apparatus *d* filled with chloride of calcium.

A long time is sometimes required for this operation, especially if there is much metallic iron; the operation is accelerated and completed by placing under the flask a spirit-lamp with a very small flame, thus at last keeping the contents for a few minutes in a boiling state. The apparatus containing the chloride of calcium is finally connected with an aspirator, and after the flask is almost filled with water, air is slowly drawn through the apparatus so that each air-bubble enters through the lower end of the funnel-tube. Any hydrogen that the potash may still contain is thus made to pass in the state of water into the apparatus filled with chloride of calcium. This being done the increase in the weight of the chlorine of calcium shows how much metallic iron the examined ore contained, for 9 units of weight of water correspond with 28 units of weight of iron.

The contents of the small flask are now carefully washed into a larger flask of $\frac{1}{2}$ litre capacity, the diluted solution being brought into a boiling state and then oxidized by the addition of pieces of chloride of potash, as previously described.

The completely oxidized solution is next washed in a bottle of $\frac{1}{2}$ litre capacity, which is very carefully measured; and exactly 100 cubic centimètres of the fluid ore are then taken for determining the total contents of iron by the action of a thin piece of copper as has been described above.

Contrary to Scheerer's statement that iron ores are always reduced at first to a state of protoxide before metallic iron is formed, I have found that peroxide even exists very often side by side with metallic iron, this being shown by the yellow colour of the fluid after the first quantity of hydrochloric acid is added to the ore; this colour, however, soon disappears, for the hydrogen

generated reduces the perchloride originally formed into protochloride of iron. The analysis gives, therefore, less metallic iron than really was in existence. In order to ascertain now by means of analysis how much oxygen has been removed by the reduction, I suggest the following calculation.

If we had found, for example, in determining the metallic iron, 0·288 gramme of water, this quantity would correspond to 0·896 gramme of metallic iron, and if the ore submitted to the analysis weighed 5·231 grammes, this would correspond to 17·1287 per cent. If the piece of copper lost in weight 0·288 gramme, the loss corresponding to the total quantity of the ore is $5 \times 0\cdot288 = 2\cdot040$ grammes of copper = 1·8075624 gramme of iron = 34·5548 per cent. of the ores analyzed.

We have thus :

Total quantity of iron	..	..	..	34·5548	
Less the metallic iron	..	..	..	17·1287	= Fe 17·1287
				<hr/>	
				17·4261	= Fe O 22·3974
				<hr/>	
				39·5261	

containing $39\cdot5261 - 34\cdot5548 = 4\cdot9713$ oxygen = 12·5773 per cent. of the oxide which had been found in the ore.

If now the ore had already been reduced by means of former treatment so far that it only contained 23·2111 per cent. of oxygen combined with iron, the quantity of oxygen separated in the last operation would be equal to $23\cdot2111 - 12\cdot5773 = 10\cdot6338$.

These numbers, which represent the final result of the analysis, signify, therefore, that from 100 parts of oxide contained in the examined ore, there have been separated so many atoms of oxygen, and these numbers refer to the volume of the ores, for the ore in the apparatus occupies always the same volume.

In order to ascertain, now, what the influence of the reducing gases upon equal weights of the ore has been, we have simply to multiply these numbers by 100, and to divide the result again by the weight of the 110 cubic centimètres of ore; the final result shows then, how much oxygen has been eliminated from the oxide of iron contained in 100 grammes of the ore.

In order to obtain, however, a better understanding of the degree of reduction, we have still to calculate what percentage

of oxygen contained in the ores has been lost through the reduction. This calculation is very simple, the number given by the analysis having only to be divided by the quantity of oxygen contained in 100 parts of oxide; for example, the oxide in red hematite iron ore contains 30 per cent. of oxygen, and in spathic iron ore 22·222 per cent. The three columns marked "oxygen eliminated" in the Tables on page 99 *et seq.* are calculated in this manner.

The first Table gives the composition of the ores used for these experiments on reduction.

The Roman figures in the column marked "number of the ore" designate the ore; the word "raw" signifies that ore was used in its natural state; and the Arabic figures indicate in which of the different experiments the same ore had previously been partly reduced. The column headed "gas passed" gives the number of the litres which were passed per hour through the apparatus. The column "CO per cent. in the gas" indicates the proportion of CO which the gas contained. The glass bell contained in reality 114·5 litres; but the temperature of this bell in the neighbourhood of the furnace was on the average 28°, and the equivalent volume of the confined gas at 0° and at a barometric pressure of 0·76 mètre of mercury would, therefore, be only 100 litres.

One hundred litres of air are equal to 79·04 litres of nitrogen plus 20·96 oxygen. The latter gives 41·92 litres of carbonic oxide, and the gases produced thus consist of:

$$\begin{array}{rcl}
 41\cdot92 \text{ CO} & = & 34\cdot656 \\
 79\cdot04 \text{ N} & = & 65\cdot344 \\
 \hline
 120\cdot96 \text{ litres,} & & 100\cdot000
 \end{array}$$

Afterwards the bell had placed in it 35 litres of pure CO, and was then filled up with the ordinary gases just mentioned, whence the composition:

$$\begin{array}{rcl}
 \left. \begin{array}{l} 35\cdot00 \text{ litres} \\ 41\cdot92 \text{ " } \\ 79\cdot04 \text{ " } \end{array} \right\} & \begin{array}{l} 79\cdot62 \text{ litres of carbonic oxide} \\ 79\cdot04 \text{ " } \text{nitrogen} \end{array} & \begin{array}{l} = 49\cdot32 \\ = 50\cdot68 \end{array} \\
 \hline
 155\cdot96 \text{ " } & & 100\cdot00 \\
 & & \text{Σ}
 \end{array}$$

Another column is added in the Tables which indicates what percentage of oxygen was eliminated per hour. The temperature in the tube of reduction was determined every quarter of an hour, and the average was taken after three hours. This mode of operating was necessary, in order to make the procedure clearer; but it is by no means rational, for the first temperatures of the tube of observation may be very low, and the others very high, and the average values will still represent an equal temperature during the whole time; I will, however, explain this when we examine the results obtained more minutely.

CHAPTER XX.

EXPERIMENTS ON REDUCTION.

THESE experiments are unfortunately still very incomplete, although they required much time and work. The difficulties consist principally in the circumstances that the ores to be examined are not uniformly reduced, and that the successively increasing temperatures are not exactly the same for different experiments; it is also impossible to maintain for several hours the uniform temperature. The reductometer should determine:

- a. The influence of the temperature;
- b. The influence of the quantity of gas in the unit of time;
- c. The influence of the proportion of carbonic oxide contained in the gases;
- d. The influence of the time;
- e. The influence of the quality of the ores, and
- f. The carburization of the iron.

One of the first of the following Tables gives the chemical composition of the ores examined; the following one gives the experiments chronologically arranged. The next Tables give the experiments for each particular ore, with particulars of the extreme temperatures; the initial temperature is generally the lower, and the final temperature the higher one.

EXPERIMENTS ON REDUCTION.

99

COMPOSITIONS OF THE ORES ANALYZED.

	Reference Nos. of the Ores.					
	I.	II.	III.	IV.	V.	VI.
oxide of iron	58·275	51·799	30·797	46·170	35·46	0·000
oxide .. ..	..	4·492	3·023	..	..	52·036
le of manganese .. ..	..	0·000	..	7·116	0·84	3·919
on	21·864	10·771	21·308	22·907	49·36	0·650
r	12·973	11·168	18·383	9·563	9·43	1·437
bonate of lime	0·666	6·537	4·243	1·393	1·10	0·602
nesium	0·430	1·273	..	1·035	0·17	4·651
ash .. ..	..	1·421	4·496	0·220	0·47	0·177
phuric acid .. ..	..	0·377	0·285	..	..	..
sphoric	2·110	2·124	0·930	0·688	0·06	..
bonic .. ..	..	5·737	5·077	0·000	..	32·490
ter	3·682	4·301	11·013	10·721	3·11	4·038
s .. ..	..	..	0·445	..	..	..
xygen in the oxides of iron and of manganese (per cent. of oxide) ..	100·000	100·000	100·000	100·000	100·00	100·000
	30·000	29·38	29·29	30·05	30·01	22·244

	VII.	VIII.	IX.	X.	XI.	XII.
oxide of iron	60·493	77·360	..	44·44	100	80
oxide .. ..	..	..	35·026	..	..	..
le of manganese .. ..	..	..	..	..	..	..
on	21·902	8·081	3·161	..	..	20
y	8·182	2·841	2·001	..	..	..
bonate of lime	1·070	0·569	45·390	44·44	..	..
nesium	1·742	0·585	0·261	..	..	..
la	0·647	0·331	carbon	carbon	..	..
ash	0·307	..	10·631	11·12	..	..
phuric acid .. ..	..	..	arsenious acid	..	..	..
osphoric	3·153	..	0·200	..	..	..
bonic .. ..	..	..	3·330	..	..	..
ter	2·504	10·233	..	..	..	..
xygen in the oxides of iron and of manganese (per cent. of oxygen) ..	100·000	100·000	100·000	100·000	100	100
	30·00	30·00	22·222	30·000	30·00	30·00

Series of Experiments.	Number of the Ore.	Gas passed.	Per cent. in the Gas.	Duration of the Experiment.		Oxygen Eliminated.				Mean Temperature.
				hours.	minutes.	Per cent. in the Oxides present.	Grammes of Oxygen per 100 gr. of Ore.	Percentage of Oxygen.	Percentage of Oxygen per hour.	
No.		Litres.	CO							
1	I. raw	26.6	34.65	3	45	4.867	1.606	14.557	3.88	609
2	III.	26.6	34.65	3	45	2.921	1.529	9.631	2.57	609
3	VII.	26.6	34.65	3	45	8.699	1.349	12.330	3.29	609
4	I. reduced	32	34.65	6	15	0.689	0.235	2.130	0.34	633
5	III.	32	34.65	6	15	2.660	1.393	9.082	1.45	632
6	VII. reduced	32	34.65	6	15	8.341	1.219	11.197	1.78	632
7	I.	33	34.65	9	..	7.1575	2.631	23.858	2.65	750
8	III.	33	34.65	9	..	5.3024	2.776	18.103	2.01	750
9	VII.	33	34.65	9	..	9.6355	8.517	32.118	3.56	750
10	I. raw	39	34.65	7	30	7.260	2.669	24.200	4.68	749
11	III. raw	39	34.65	7	30	6.322	8.310	21.584	4.18	749
12	VI.	39	34.65	7	30	0.1826	0.096	0.8209	0.16	749
13	II.	36	34.65	5	28	1.7547	0.844	5.972	1.09	622
14	IV.	36	34.65	5	28	2.8535	1.502	9.496	1.74	622
15	V.	36	34.65	5	28	0.363	0.220	1.209	0.22	622
16	II. reduced	38	34.65	7	55	12.0428	5.789	40.989	5.18	800
17	IV.	38	34.65	7	55	10.7122	5.688	35.648	4.50	800
18	V.	38	34.65	7	55	12.792	7.758	42.626	5.38	800
19	VIII. raw	25	34.65	8	..	9.102	8.216	30.340	8.79	786
20	XI.	25	34.65	8	..	7.7248	7.7248	25.749	8.22	786
21	VIII.	25	34.65	4	..	1.9885	0.685	6.462	1.60	421
22	VIII. reduced	25	34.65	6	..	4.5881	1.617	15.294	2.55	594
23	VII.	25	34.65	8	..	6.4384	2.294	21.645	2.70	842

24	VIII. reduced	23	25	84·65	4	..	5·8422	1·888	17·807	4·45	884
25	X. raw		25	84·65	4	..	12·8620	12·8620	41·207	10·30	884
26	VIII. "		25	84·65	9	..	12·8421	4·538	42·807	4·75	890
27	VIII. "		46·6	84·65	9	..	15·1704	5·361	50·568	5·62	759
28	VIII. reduced	27	50	84·65	4	..	3·1511	1·113	10·504	2·62	000
29	VIII. raw		33·33	84·65	9	..	12·0156	4·246	40·052	4·45	666
30	VIII. reduced	29	33·33	84·65	9	..	9·6289	3·402	32·096	3·56	868
31	VII. raw		33·33	84·65	9	..	15·6598	5·715	52·198	5·80	648
32	II. "		33·33	84·65	4	30	4·7958	2·306	16·323	3·62	513
33	II. reduced	32	33·33	84·65	9	..	5·84999	2·812	19·911	2·21	742
34	XI. raw		33·33	84·65	6	..	7·7388	7·7388	25·796	4·30	561
35	XI. reduced	33	33·33	84·65	9	..	12·362	12·362	41·207	4·58	745
36	X. raw		33·33	84·65	9	..	18·1166	9·0583	60·388	6·71	591
37	III. "		33·33	34·65	9	..	10·5204	5·508	35·918	4·00	591
38	III. reduced	36	33·33	34·65	9	..	0·693	0·363	2·366	0·26	772
39	III. "	37	33·33	84·65	4	..	9·2071	4·820	31·434	7·86	866
40	IV. raw		33·33	34·65	9	..	7·431	3·911	24·729	2·75	623
41	IV. reduced	39	33·33	84·65	6	..	14·5612	7·664	48·456	8·07	802
42	V. raw		33·33	84·65	9	..	6·8508	4·152	22·828	2·53	605
43	V. reduced	41	33·33	34·65	6	..	9·0170	5·461	30·465	5·08	782
44	IV. "	40	33·33	84·65	9	..	5·3038	2·734	17·650	1·96	736
45	VI. raw		33·33	84·65	6	..	15·7514	8·119	70·812	11·80	735
46	VI. reduced	42	33·33	84·65	4	..	22·244	11·455	100·000	25·00	862
47	XI. "		33·33	84·65	9	..	0	0	0	0	404
48	XI. reduced	46	33·33	34·65	9	..	6·5244	10·874	21·718	2·41	535
49	XII. "	47	33·33	84·65	9	..	7·7879	7·7879	25·960	2·88	535
			33·33	84·65	9	..	2·4122	4·020	8·047	0·89	781

THE BLAST-FURNACE.

TABLE continued.

Series of Experiments.	Number of the Ore.	Gas passed.	Percent. in the Gas.		Loss. in the Experiment.	Percent. in the Gas as a whole.	Oxygen Estimated.			Weight of the substance.
			Bicarb.	CO			Grammes of Oxygen per 100 gr. of the gas.	Percentage of Oxygen in the gas.	Weight of the substance.	
No.					loss. in the gas.					
50	XI. reduced 48	33-33	34-65	9	..	6-9210	6-8210	22-713	2-53	781
51	XII. " 49	33-33	34-65	9	..	1-430	2-483	4-967	0-55	781
52	II. raw 33-33	33-33	34-65	9	..	6-3173	3-003	21-502	2-39	512
53	II. reduced 52	33-33	33-65	9	..	18-6953	8-975	63-541	7-06	794
54	XI. raw 33-33	33-33	57-0	6	..	11-8504	11-8504	39-631	6-60	629
55	XI. reduced 54	33-33	61-0	6	..	2-0063	2-0063	6-667	1-11	787
56	XI. raw 33-33	33-33	100	3	..	9-3810	9-3810	31-270	10-42	755
57	VIII. " 33-33	33-33	49-32	6	..	4-3729	1-515	14-576	2-13	783
58	VIII. reduced 57	33-33	49-32	6	..	17-2214	6-085	44-071	7-34	896
60	VIII. raw 33-33	33-33	49-32	6	..	6-330	2-258	21-300	3-55	791
61	VIII. raw 33-33	33-33	49-32	6	..	5-9018	2-085	19-673	3-28	679
62	VIII. reduced 61	33-33	49-32	3	..	20-0749	7-058	66-916	22-30	898
63	VIII. " 60	33-33	49-32	3	..	18-5398	6-551	61-709	20-59	982
64	VIII. raw 33-33	33-33	49-32	6	..	5-964	2-107	19-880	3-31	546
65	VIII. " 33-33	33-33	49-32	3	..	7-7171	2-727	25-724	8-57	663
bis										
65	VIII. reduced 65	33-33	49-32	3	..	8-3975	2-967	27-992	9-83	875
66	VIII. " 64	33-33	49-32	3	..	12-2667	4-335	40-881	13-63	817
67	X. raw 33-33	33-33	49-32	6	..	26-2161	52-432	87-387	14-57	676
68	XI. " 33-33	33-33	49-32	6	..	10-7865	10-7825	35-942	5-99	736
69	XI. reduced 68	33-33	49-32	3	..	3-7087	3-7087	12-362	4-12	907
70	VII. raw 33-33	33-33	49-32	6	..	7-8498	2-774	26-166	4-86	765
71	VI. " 33-33	33-33	49-32	9	..	0	0	0	0	761

ORE No. I.—RED HEMATITE IRON ORE FROM NASSAU.

Specific gravity = 4·288.

Series of Experiments.	Duration of the Experiment.		Gas per hour.	Percentage of CO in the Gas.	Temperatures in degrees.	Oxygen eliminated.	
						Total per cent.	Per hour per cent.
No. 1	hours. 3	minutes. 45	litres. 26·6	34·65	609	14·557	3·88
4	6	15	32	34·65	597 and 667	2·130	0·34
7	9	0	33	34·65	730 „ 771	23·858	2·65
	19	0				40·545	2·13
10	7	30	39	34·65	707 and 793	24·200	4·68

ORE No. II.—BROWN IRON ORES FROM HAYANGE.

Specific gravity = 3·9589.

Series of Experiments.	Duration of the Experiment.		Gas per hour.	Percentage of CO in the Gas.	Temperatures in degrees.	Oxygen eliminated.	
						Total per cent.	Per cent. per hour.
No. 13	hours. 5	minutes. 28	litres. 36	34·65	614 and 630	5·972	1·09
16	7	55	38	34·65	785 „ 819	40·989	5·18
	13	23				46·961	3·51
32 bis	4	30	33·33	34·65	571 and 456	16·323	3·62
32	9	0	33·33	34·65	608 „ 827	19·911	2·21
	13	30				36·234	2·68
52	9	0	33·33	34·65	530 and 549	21·502	2·39
53	9	0	33·33	34·65	723 „ 877	63·541	7·06
	18	0				85·043	4·72

ORE No. III.—BOHN-ERZ FROM NEUBOURG.

Specific gravity = 3·6550.

Series of Experiments.	Duration of Experiment.		Gas per hour.	Percentage of CO in the Gas.	Temperatures in degrees.	Oxygen eliminated.	
						Total per cent.	Per cent. per hour.
No.	hours.	minutes.	litres.				
2	3	45	26·6	34·65	609	9·631	2·57
5	6	15	32	34·65	597 and 667	9·082	1·45
8	9	0	33	34·65	730 „ 771	18·103	2·01
	19	0				36·816	1·99
11	7	30	39	34·65	707 and 793	21·584	4·18
36	9	0	33·33	34·65	454 and 685	35·918	4·00
37	9	0	33·33	34·65	698 „ 842	2·366	0·26
38	4	0	33·33	34·65	865 „ 867	31·434	7·86
	22	0				69·718	6·17

ORE No. IV.—BROWN IRON ORES FROM NASSAU.

Specific gravity = 3·6409.

Series of Experiments.	Duration of Experiment.		Gas per hour.	Percentage of CO in the Gas.	Temperatures in degrees.	Oxygen eliminated.	
						Total per cent.	Per cent. per hour.
No.	hours.	minutes.	litres.				
14	5	28	36	34·65	614 and 630	9·496	1·74
17	7	55	38	34·65	785 „ 819	35·648	4·50
	13	23				45·144	3·37
39	9	0	33·33	34·65	513 and 737	24·729	2·75
40	6	0	33·33	34·65	729 „ 874	48·456	8·07
43	9	0	33·33	34·65	701 „ 792	17·650	1·69
	24	0				90·835	3·75

EXPERIMENTS ON REDUCTION.

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ORE NO. V.—BOHN-ERZ FROM MORSCHWEILER.

Specific gravity = 3.1570.

Series of Experiments.	Duration of Experiment.		Gas per hour.	Percentage of CO in the Gas.	Temperatures in degrees.	Oxygen eliminated.	
						Total per cent.	Per cent. per hour.
No. 15	5	28	36	34.65	614 and 630	1.209	0.22
18	7	55	38	34.65	785 " 819	42.626	5.38
	13	23				43.835	3.27
41	9	0	33.33	34.65	497 and 701	22.828	2.53
42	6	0	33.33	34.65	692 " 871	30.465	5.08
	15	0				53.293	3.55

ORE NO. VI.—SPATHIC IRON ORES FROM SIEGEN.

Specific gravity = 3.7159.

Series of Experiments.	Duration of Experiment.		Gas per hour.	Percentage of CO in the Gas.	Temperatures in degrees.	Oxygen eliminated.	
						Total per cent.	Per cent. per hour.
No. 12	7	30	39	34.65	707 and 793	0.8209	0.16
44	6	0	33.33	34.65	640 " 829	70.812	11.80
45	4	0	33.33	34.65	840 " 882	100	25
71	9	0	33.33	34.65	729 " 792	0	0

ORE NO. VII.—OOLITHIC ORES FROM NAMUR.

Specific gravity = 5.2316.

Series of Experiments.	Duration of Experiment.		Gas per hour.	Percentage of CO in the Gas.	Temperatures in degrees.	Oxygen eliminated.	
						Total per cent.	Per cent. per hour.
No. 3	3	45	26.6	34.65	609	12.330	3.29
6	6	15	32	34.65	597 and 667	11.137	1.78
9	9	0	33	34.65	730 " 771	32.118	3.56
	19	0				55.585	2.93
81	9	0	33.33	34.65	461 and 830	52.198	5.80
70	6	0	33.33	49.32	580, 829, 885	26.166	4.36

ORE No. VIII.—RED HEMATITE IRON ORES FROM DILLENBOURG.

Specific gravity = 5.4072.

Series of Experiments.	Duration of Experiment.		Gas per hour.	Percentage of CO in the Gas.	Temperatures in degrees.	Oxygen eliminated.	
	hours.	minutes.				Total per cent.	Per cent. per hour.
No. 19	8	0	25	34.65	654 and 809	30.340	3.79
21	4	0	25	34.65	421	6.462	1.60
22	6	0	25	34.65	546 and 621	15.294	2.55
23	8	0	25	34.65	823 „ 861	21.645	2.70
24	4	0	25	34.65	884	17.807	4.45
	22	0				61.208	2.78
26	9	0	25	34.65	720 and 897	42.807	4.75
27	9	0	46.6	34.65	499 and 819	50.568	5.62
28	4	0	50	34.65	883 „ 910	10.504	2.62
	13	0				60.072	4.62
29	9	0	33.33	34.65	472 and 825	40.052	4.45
30	9	0	33.33	34.65	842 „ 897	32.096	3.56
	18	0				72.148	4.01
57	6	0	33.33	49.32	554 and 562	14.576	2.43
58	6	0	33.33	49.32	791 „ 799	44.071	7.34
	12	0				58.647	4.88
60	6	15	33.33	49.32	753 and 828	21.300	3.55
63	3	0	33.33	49.32	928 „ 1041	61.799	20.59
	9	15				83.099	9.68
61	6	0	33.33	49.32	571 and 787	19.673	3.28
62	3	0	33.33	49.32	898	66.916	22.30
	9	0				86.589	9.62
64	6	0	33.33	49.32	484 and 609	19.880	3.31
66	3	0	33.33	49.32	817	40.881	13.63
	9	0				60.761	6.75
65 bis	3	0	33.33	49.32	663	25.724	8.57
65	3	0			908 and 976	27.992	9.33
	6					53.716	8.95

ORE No. X.—ARTIFICIAL ORES.

100 Oxide of iron; 100 Carbonate of lime; 25 Carbon.

Series of Experiments.	Duration of Experiment.		Gas per hour.	Percentage of CO in the Gas.	Temperatures in degrees.	Oxygen eliminated.	
	hours.	minutes.				Total per cent.	Per cent. per hour.
No. 25	4	0	litres. 25	34·65	884	41·207	10·30
35	9	0	33·33	34·65	458 and 719	60·388	6·71
67	6	0	33·33	49·32	583 „ 792	87·387	14·57

ORE No. XI.—ARTIFICIAL ORES. BALLS OF PURE OXIDE OF IRON.

Series of Experiments.	Duration of Experiment.		Gas per hour.	Percentage of CO in the Gas.	Temperatures in degrees.	Oxygen eliminated.	
	hours.	minutes.				Total per cent.	Per cent. per hour.
No. 20	8	0	litres. 25	34·56	654 and 809	25·749	3·22
33	6	0	33·33	34·56	503 and 619	25·796	4·30
34	9	0	33·33	34·56	674 „ 808	41·207	4·85
	15	0				67·003	4·46
46	9	0	33·33	34·56	417 and 398	0	0
48	9	0	33·33	34·56	517 „ 547	25·960	2·88
50	9	0	33·33	34·56	780 „ 786	22·743	2·53
	18	0				48·703	2·71
54	6	0	33·33	57	569 and 687	39·634	6·60
55	6	0	33·33	61	765 „ 809	6·667	1·11
	12	0				46·301	3·86
56	3	0	33·33	100	755	31·270	10·42
68	6	0	33·33	49·32	571 and 871	35·942	5·99
69	3	0	33·33	49·32	907	12·362	4·12
	9	0				48·304	5·37

ORE No. XII.—ARTIFICIAL ORES.

Balls formed of $\left\{ \begin{array}{l} 20 \text{ silicic acid.} \\ 80 \text{ pure oxide of iron.} \end{array} \right.$

Series of Experiments.	Duration of Experiment.		Gas per hour.	Percentage of CO in the Gas.	Temperatures in degrees.	Oxygen eliminated.	
						Total per cent.	Per cent. per hour.
No.	hours.	minutes.	litres.				
51	9	0	33·33	34·65	417 and 398	0	0
47	9	0	33·33	34·65	517, 542, & 547	21·748	2·41
49	9	0	33·33	34·65	781 and 780	8·047	0·89
	27	0				81·795	1·76

CHAPTER XXI.

RESULTS OF THE REDUCTOMETRIC OBSERVATIONS.

a.—Influence of the Temperature.

It is noticeable, as a general result, that low temperatures are less powerful in effecting reduction than higher ones, and also that the last atoms of the oxygen in the ores are much more difficult to eliminate than the first ones. The following comparison shows this very clearly :

ORE No. VIII.

Experiment No.	Absorption per hour.	Temperatures.
21	1·60	421°
22	2·55	between 546 and 621°
23	2·70	" 823 " 861°
24	4·45	884°

b.—Quantity of Gas in the Unit of Time.

In experiment No. 26, the quantity of gas passed through the apparatus per hour was 25 litres, the temperature between 720° and 897°, and quantity of oxygen absorbed per hour = 4·75 per cent.

On the other hand, during experiment No. 27, the quantity of gas passed through per hour was 46·6 " the temperature

between 499° and 819° , and the absorption per hour = 5.62 per cent.

We thus see that notwithstanding that the temperature in No. 27 was less than in No. 26, the favourable absorption was greater than in the latter case, on account of the larger quantity of gas passed through the apparatus in a given time.

c.—Proportion of Carbonic Oxide in the Gases.

If a larger quantity of gas in a given time favours the reduction, an increase in the proportion of the carbonic oxide produces a still greater effect, as proved by the experiments. Adding together the parts of the experiments with the ore No. VIII, from 19 to 30, and also those from 57 to 65, we get:

Hours.	Gas per hour.	Percentage of CO.	Temperature, Degrees.	Absorption.
8	25	34.65	654	
			809	30.340
22	25	34.65	421	
			884	61.208
9	25	34.65	720	
			897	42.807
13	48.3	34.65	499	
			819	60.072
18	33.3	34.65	472	
			897	72.148
<hr/> 70	<hr/> 156.6		<hr/> 7072	<hr/> 266.575
70	5		10	70
Average 1	31.3		707.2	3.808
Hours.	Gas per hour.	Percentage of CO.	Temperature, Degrees.	Absorption.
18	33.33	49.32	554	
			799	58.647
9½	33.33	49.32	753	
			1041	83.099
9	33.33	49.32	571	
			898	86.589
9	33.33	49.32	484	
			817	60.761
6	33.33	49.32	663	
			976	53.716
<hr/> 45	<hr/> 166.65		<hr/> 7556	<hr/> 342.812
45	5		10	45
Average 1	33.33		755.6	7.618

The reduction effected by the gas containing 49·32 per cent. of carbonic oxide was, therefore, just twice as rapid as that caused by the gas containing 34·65 per cent., whilst the temperature of the latter was but 48° lower, and the absolute quantity per hour only 2 per cent. less than for the former gas. These experiments justify the supposition that with gases containing more than 51 per cent. of CO—which can be produced, as we shall show presently—the rate of reduction will be doubled; or what is the same thing, that one hour will be sufficient for producing the same effect as it required two hours to obtain with gases containing the ordinary proportion of CO.

d.—Influence of Time.

This influence is predominant in all the experiments; of course, that is nothing new, but it is, therefore, not less important; for the practical success of the blast-furnace, as at present worked, depends chiefly upon the exact measurement of the time for the reduction of the ores.

e.—Quality of the Ores.

The minerals I., III., and VII., red hematite, Bohn-Erz, and oolitic ores, containing 58, 30·8, and 60·5 per cent. of oxide of iron, were exposed in the experiments 1 to 9, to the current of gas for 3½ hours, then 6¼ hours, and finally for 9 hours, at temperatures between 609° and 771°, and the total absorption of oxygen per 100 grammes of the minerals was, respectively, 4·472 per cent., 5·698 per cent., and 6·085 per cent. The specific gravities of these minerals were respectively, 4·2, 3·6, and 5·2, whence it follows that neither the contents of iron nor the specific gravity of the minerals bear any fixed relation to the rate of reduction, and that the manner in which each mineral acts, has to be determined by special experiments.

The coefficients of reduction of these three minerals were, according to the volume, = 40·5, 36·8, and 55·6; which corresponds with the proportions 1·10, 1·00, and 1·51. The richest and most compact mineral gives thus, under all circumstances, the most favourable coefficient; and this is important, because

it shows that richer ores can be reduced more quickly when the diminution of time is compensated for by the use of richer gases.

f.—Carburization of the Iron.

Many methods are known of determining the contents of carbon in the pig-iron; I have proved them all, and consider that for half-reduced ores that of Ullgren is the best, for it requires the least time, and can easily be carried out with accuracy if care is taken to add a sufficient quantity of chromic acid, in order to prevent the formation of sulphurous acid.

The apparatus used for this purpose is represented by Figure 19, in which *a* is the small bottle in which the mineral is at first treated with sulphate of copper, and where it afterwards has sulphuric acid poured over it.

I next drew into the bottle *a*, through the tube *b*, a very strong solution of chromic acid, the tube *b* being closed again directly after this had been done. The tube *c* is a large bent pipette; the apparatus *d* is filled with pumice-stone and sulphuric acid, the tube *e* with chloride of calcium, the tube *f* with lime, and the tube *g* with hydrate of potash. When, after a prolonged ebullition of the contents of *a*, all reaction is over, the tube *g* is connected to an aspirator, the tube *b* again opened, and 5 litres of air are drawn through. The additional weight obtained in the tubes *f* and *g* gives the amount of carbonic acid produced, whence can be calculated the amount of carbon which existed in the mineral under analysis. The results obtained from these analyses do not agree very well, as will be seen from the following comparison :

Mineral No.	Experiment No.				
II.	..	53	gave, per 100 of reduced iron,		
IV.	..	40	0.2377 of carbon.		
VI.	..	44	"	"	"
VIII.	..	23	"	"	"
"	..	24	"	"	"
"	..	26	"	"	"
"	..	27	"	"	"
"	..	28	"	"	"
"	..	30	"	"	"
"	..	63	"	"	"
XI.	..	50	"	"	"

The greater percentages seem all to be caused by a proportionately slow reduction produced by an insufficiently quick increase of the temperature, this state of affairs allowing the carbon to combine with the iron, instead of reducing it. These experiments show, however, that in all cases the carburization of the iron begins as soon as metallic iron is formed; and that the greater the percentage of carbonic oxide in the gas, the greater is the transfer of carbon to the iron, when the reduction of the latter is completed; experiment No. 63 is an example of this. That a high temperature is not necessary for carburization is shown by experiment No. 50, where a considerable carbonization took place at a temperature between 780° and 786° , at a time when only half the existing iron had been reduced.

CHAPTER XXII.

ZONES OF THE BLAST-FURNACE.

SCHEERER has, in a very clear manner, divided the blast-furnace into zones of combustion, of fusion, of carburization, of reduction, and of preparation, and he has fixed the limits of temperatures for these several zones as being between 2650° and 2000° , 2000° and 1200° , 1200° and 400° , and 400° and the temperature of the escaping gases, respectively. Of course, these hypotheses are more or less arbitrary, for some fixed starting-point was wanted. I have endeavoured by means of experiments to obtain some base for such a division of the zones, and to especially determine their volume as exactly as possible. The aim of the studies on surface of contact and influence of the temperature when carbonic acid is reduced to carbonic oxide, was chiefly for the more exact determination of the volume of the zone of gasification. This determination, however, can only be an approximate one for reasons already explained.

The experiments made with the reductometer do not seem to justify any distinction between the zone of fusion and that of

carburization, for the carburization begins at a low temperature with the reduction of the first molecules of metallic iron.

I have not made any special experiments for determining the points of fusion of the iron ; I think those by Pouillet deserve full confidence, for all my pyrometric experiments have proved to me that all previous determinations of points of fusion at high temperatures have been much too high. The point of fusion of the least fusible pig-iron is, according to Pouillet, 1250 degrees centigrade, and even that number appears to be almost too high. Of course the points of fusion of the slags vary very much, according to the proportion of protoxide of iron which the latter contain, and I have seen those slags containing much of the peroxide formed and begin to run at temperatures between 900° and 1000°. Glass that is fusible with difficulty gets soft at 769°, and when suspended is drawn into threads by its own weight ; while at 1052° it is perfectly fluid. These facts prove that the zone of fusion cannot have for its limits the temperatures 2000° and 1200°, for the commencement of the fusion, that is to say the softening of the mass (iron and slags) certainly commences at a much lower temperature than that last mentioned.

The combustion of the carbon—half of which burns at first to carbonic acid and then, by absorbing the other half, forms carbonic oxide—does not give a temperature higher than 1400° or 1500°, and the limit of the zone of gasification cannot, therefore, be taken higher ; this temperature is amply sufficient to effect the fusion of the iron and slags, their points of fusion being, at a maximum, 1250° or 1300°, and the materials being moreover already at a high temperature. Nevertheless, the temperature of the zone of fusion at its lower limit must be higher than the point of fusion of the material, for at this point the latent heat required for the fusion of the material must be supplied, the consequence of this being that the temperature is liable to be suddenly decreased.

Such a decrease of the temperature was some time ago observed by Ebelmen at the point where the limestone loses its carbonic acid, and where a certain quantity of the heat of combination has thus to be restored. I have also very often observed during my

experiments on reduction that when marble was added to the ores, the pyrometer, after showing a gradually increasing temperature, suddenly went back considerably, and it was only after some time had elapsed that it again showed an increase of the temperature. This phenomenon only occurred between 800° and 900° , the temperature at which the carbonic acid was expelled from the marble.

My own experiments have further shown that, in absence of the lime, the ores, when at a temperature of 800° , already began to be mixed with softened silicates of protoxide of iron. This formation of silicates was not so apparent when lime was present, for the lime disappeared partly and penetrated the pieces of ores, increasing their volume without altering their shape. The pieces of ores thus penetrated were porous, and could easily be crushed.

This action, however, is not carried on to the same extent in the real blast-furnace, for the pieces of ores and limestone are there very much larger than in my experiments on reduction, whilst the time during which they can act upon each other remains almost the same; and thus the inner parts of the pieces of ore are less reduced than the outer, and a portion of the existing protoxide will always combine with silicious acid, as soon as the charge acquires a temperature which exceeds 800° and before the ores can be penetrated by the lime.

The analyses of the gases collected at different depths in the blast-furnace show further that these gases contain but very little carbonic acid, even when the depth from which they are drawn is below that at which the carbonic acid is separated from the limestone; and this proves that the reduction effected by the carbonic oxide is of but little importance below the temperature of 800° , and it has not to be considered as a completion of the reduction, but as a more or less accidental consequence. It follows from these facts and observations that the temperature of the upper limit of the zone of fusion cannot be supposed to be higher than 800° , so that the decomposition of the limestone must take place in the zone of reduction.

Even if it is possible to reduce the ore with pure CO at low temperatures, it is not the same with the gases of the blast-

furnace, for the experiments have shown that this reduction is very feeble at 500° and becomes *nil* at 400° , so that the upper limit of the zone of reduction cannot, therefore, be taken below 500° .

The zone of fusion will thus be limited : below by the highest temperature of the zone of gasification, above, by the temperature of 800° ; while the limits of temperature of the zone of reduction are 800° and 500° , and those of the zone of preparation, in which the water contained in the charges is evaporated, are 500° and the temperature of discharge.

The volume of the zone of gasification is not determined by the limits of temperature, but by that volume of the pieces of fuel which corresponds with a surface of contact of 13 square mètres for each cubic metre of blast entering the furnace per second.

CHAPTER XXIII.

VOLUME OF THE ZONE OF GASIFICATION.

We call this zone the "zone of gasification" and not that of combustion, because the combustion consists only in the formation of carbonic acid, which is subsequently reduced to carbonic oxide. The zone of combustion, properly so called, is not separated from that in which carbonic oxide is formed, because the former could scarcely be determined with any probability; we know only that it is very small.

We have seen in Chapter IV. that we may suppose, with the greatest probability, that an amount of carbonic acid which, with the temperature existing in the hearth of the furnace, requires one square mètré of surface of contact for its formation, will require for its reduction 12 square mètres of contact surface; but we can only determine approximately how large this surface of contact is in reality.

We may suppose that the pieces of fuel contained in the charges have, on the average, a sectional area of 6 square centimètres; but when these pieces arrive at the hearth of the furnace

where their carbon is transformed into carbonic acid, they will be reduced to at least half of their former volume. If we suppose these pieces to be spheres, one cubic mètre will, according to Chapter III., contain 37038 of such spheres, and each of them will have an area or surface of contact of 0.0028274 square mètre; one cubic mètre of spheres, therefore, will give = 104.72 square mètres of surface of contact.

If now, for example, as in the blast-furnace of Clairval (Chapter XXXV.), 0.11356 cubic mètre of air enters the furnace per second, and if this quantity of air requires:—1 cubic mètre : 13 square mètres :: 0.11356 cubic mètre : x = 1.47628 square mètre of surface of contact, we get the volume of this zone:—104.72 square mètres : 1 cubic mètre :: 1.47628 square mètre : x = 0.0141 cubic mètre. But the upper diameter of the hearth of this furnace was 0.62 mètre, the lower diameter 0.44 mètre, and the height 0.44 mètre; thus the average section of the hearth = 0.2819 square mètre, and the capacity = 0.124036 cubic mètre. The volume of the zone of gasification would thus occupy $\frac{1}{8}$ of the hearth. This result of the calculation does not appear to be very probable, but the improbability does not prove that our calculation, based upon careful experiments, is incorrect, and not even that our assumption of the diameter of the pieces of fuel is a mistake. This apparent improbability is due to the circumstance that a portion of the hearth is not occupied by pieces of fuel, because the pressure of the blast prevents them from falling down; this can sometimes be observed with the eye, but the best proof of it is the never-failing occurrence, which happens when the blast is shut off. The materials of the charge then always sink considerably, but more or less according to the proportion between the section of the throat and the hearth of the furnace. It has been observed in one of Raschette's furnaces charged with charcoal, and in which the proportion between the section of the throat and that of the hearth is as large as $15 : 4 = 1 : 0.26$, that the charges in the throat sink as much as 0.3 mètre on the shutting off of a blast having a pressure of 0.04 mètre of mercury at the most. It follows, therefore, that there must have been a space of about 1 mètre height unoccupied by charcoal. Of course

this phenomenon depends upon different circumstances, such as pressure of the blast, density of the fuel, the mechanical resistance to the sinking of the column of fusion, due to the form of the hearth and boshes, the size of the pieces, and the nature of the charge; but the circumstance that this phenomenon can occur in such a regular and marked manner in a Raschette furnace proves that it must take place in all blast-furnaces.

Of course, we cannot calculate this space, but we may assume, without prejudicing the approximate determination of the volume of the other zones, that the zone of gasification in furnaces provided with a hearth occupies the whole capacity of that hearth, while in furnaces without a hearth it occupies $\frac{1}{3}$ of the whole height of the furnace, measured from the tuyeres to the throat.

CHAPTER XXIV.

CALCULATION OF THE TEMPERATURES IN THE ZONE OF GASIFICATION.

WHETHER we burn in the furnace in the unit of time 0.01 kil., 1 kil., 10 kils., or 100 kils. of carbon, the temperature, T , produced will always be equal to $\frac{W}{w}$, if W = quantity of heat produced, and w = specific heat of the products of combustion; for the carbon, burnt with the correct proportion of air to carbonic acid, produces always a quantity of heat proportionate to its weight, and the same with the products of combustion. It is, however, a fact that indefinitely great differences of temperature occur in different fires. The causes of these enormous differences are to be found :

1. Chiefly in the quantity of heat which is lost by transmission.
2. In the excess of air contained in the products of combustion; this case, however, cannot happen in the blast-furnace, and we have not, therefore, taken it into consideration.

3. In the preliminary heating of the fuel, which takes place especially in the blast-furnace.
4. In the more or less considerable pressure which acts upon the products of combustion.
5. In the mixture of the products of combustion with other bodies, as, for example, with moisture carried in by the air.

We have already considered, generally, the values of these factors in Chapters V., VI., VII., and XV., and we shall now only show in what manner these values have to be combined for a final result. If the transmission could be calculated *a priori*, it would be possible to introduce it into the general formula; but that is not the case, and we must therefore calculate the initial temperature, or if preferred, the theoretical temperature; next examine what is the total quantity of the transmitted heat, and finally distribute this quantity over the parts of the surface of the walls according to temperatures obtained.

There remains, then, only to introduce the three last factors into the formula, which gives the initial temperature. This formula is:

$$T = \frac{(W_o - W_n) \frac{1}{1 - \frac{s}{w n}}}{w n} \left(1 + \frac{p}{B}\right).$$

W_o is the quantity of heat produced by the carbon which is burnt to carbonic acid. But the air necessary for the combustion contains always a certain amount of moisture which is transformed in the hearth into carbonic oxide and hydrogen; and a part of the carbon is, therefore, appropriated by the water contained in the air.

Let us suppose that the average amount of water contained in the air is 9 grammes per cubic mètre, then one cubic mètre contains:

$$\left. \begin{array}{l} 0.299326 \text{ kil. of oxygen} \\ 0.98534 \text{ „ of nitrogen} \end{array} \right\} \begin{array}{l} \text{originating from the air,} \\ \text{and} \end{array}$$

0·008 kil. of oxygen } originating from the water.
 0·001 „ of hydrogen }

The carbon to be consumed will therefore burn to carbonic acid and carbonic oxide in the proportion 0·299326 : 0·008, and taking this carbon = 1, then there will be produced

0·9493 kil. of carbonic acid, and
 0·0507 „ of carbonic oxide.

 1·0000

0·9493 kil. of carbon requires for the formation of C O^2 2·53146 kils. O,
 which carry with them into the products of combustion 8·51894 „ N

 11·05040 „ of air,

which correspond with $\frac{11·0504}{1·29366} = 8·4650$ cubic mètres, and contain $8·4650 \times 0·009 = 0·076185$ kil. of water, consisting of 0·067721 kil. of oxygen and 0·008464 kil. of hydrogen.

The 0·9493 kil. of carbon, burnt to carbonic acid, produces by its combustion $0·9493 \times 8000 = 7594$ calories; but the 0·008464 kil. of hydrogen which is set free absorbs 0·008464 \times 34000 = 288 calories, which have to be deducted. There remain thus 7306 calories.

But if these first products of combustion are further transformed into carbonic oxide, absorbing just as much carbon as that previously contained (that is to say, 0·9493 kil.), 2400 calories will be absorbed per kil. of carbon, and we get $0·9493 \times 2400 = 2278$ calories, which are absorbed, and which are represented in the formula by $W n$.

The products of combustion are thus changed into :

4·54848 C O } having the { 1·127550 }
 0·008464 H } specific heats { 0·028816 } = 3·234966 = wn ,
 8·51894 N } { 2·078600 }

whence the temperature = $\frac{7306 - 2278}{3·234966} = 1554^\circ \text{ C.}$, without

taking into consideration the preliminary heating and the pressure.

For the calculation of these latter factors we have, according to Chapter X., for $T = 1550$, for coke = 0.438043 , for charcoal = 0.27918 ; for barometric pressure $B = 0.76$, and for manometric pressure $p = 0.06$. Whence

$$\begin{aligned} \text{For coke} \quad T &= \frac{(7306 - 2278) \frac{1}{1 - \frac{0.438043}{3.234966}}}{\frac{5028 \times 1.1566}{3.234966} \times 1.0789} \left(1 + \frac{0.06}{0.76}\right) = 1929^\circ \text{C.} \\ \text{For charcoal} \quad T &= \frac{(7306 - 2278) \frac{1}{1 - \frac{0.27918}{3.234966}}}{\frac{5028 \times 1.0944}{3.234966} \times 1.0789} \left(1 + \frac{0.06}{0.76}\right) = 1835^\circ \text{C.} \end{aligned}$$

But we shall see that these temperatures are considerably reduced by the transmission through the walls of the hearth of the furnace.

CHAPTER XXV.

CALCULATION OF THE VOLUMES OF THE ZONES OF FUSION, REDUCTION, AND PREPARATION.

WE have seen, in Chapter XV., how considerable is the quantity of heat that is transmitted through the walls of the furnace. The omission of this important factor is the cause of its having been impossible until now to establish an account of the heat in the furnace and of such great mistakes having been made in calculating the temperatures. In order to determine the effective temperatures in the blast-furnace, the heat transmitted must be first deducted from the heat produced. This can be done, at least approximately, in the following manner

We shall choose as an example for the purpose of explanation a blast-furnace at Seraing, charged with coke, and described by Ebelmen.

The capacity of the shaft of this furnace, measured from the hearth, that is to say, from above the tuyere holes, is 113·806 cubic mètres. The charges consist of 650 kils. of ores and 650 kils. of refinery slags (both of the same degree of richness, so that they may consequently be considered as 1300 kils. of ores) and also of 450 kils. of limestone and 800 kils. of coke.

These quantities produce :

546 kils. of pig-iron, taken as a unit	.. .. = 1	} = 2·381 ores,
754 " slag .. .. .	.. .. = { 1·381	
450 " limestone = 252 CaO and 198 CO ²	= { 0·824	} = 2·205 slag,
24 " water in the coke .. .. .	.. .. = 0·044	
48 " cinders .. .. .	.. .. = 1·465	} coke.
728 " carbon .. .. .	.. .. = 1·333	

Neglecting at first the percentage of water in the blast,

we get the heat produced .. $= \frac{1·333}{2} \times 8000 = 5333$ calories,

from which has to be deducted, for the reduction

of CO² into CO $= \frac{1·333}{2} \times 2400 = 1600$..

There remain 3733 calories;

to which are again added, by the preliminary

heating of the coke to 2000° = 2000 ×

1·465 × 0·331497 = 971 ..

From the zone of gasification originate, therefore, 4704 calories.

The products of combustion and their specific heats are :

CO	3·111 kils. × 0·2479	= 0·77123	} 2·19913,
N	5·825 " × 0·244	= 1·42790	

whence the temperature at the limit of the zone of gasification

would be $= \frac{4704}{2·19913} = 2139^{\circ} \text{C.}$; this temperature is, however,

much reduced by the transmission through the walls of the furnace. Supposing now the average temperature in the hearth of the furnace to be equal to 2100° ,

$$\text{That of the zone of fusion will be} \quad \dots \quad \frac{2100 + 800}{2} = 1450^{\circ}$$

$$\text{That of the zone of reduction} \quad \dots \quad \frac{800 + 500}{2} = 650^{\circ}$$

$$\text{And that of the zone of preparation} \quad \dots \quad \frac{500 + 100}{2} = 300^{\circ}$$

If the thickness of the walls is everywhere the same, and if the latter have, moreover, the same kind of surface and the same heat-conducting power at each zone, we get from the formula

$$t' = \frac{t - t''}{1 + Q \frac{e}{C}} + t'' \quad (\text{see Chapter XXVI.})$$

the values of the transmission for the unit of time and surface :

Temperature of the surface of the outside

 wall $t' = \dots \dots \dots 183^{\circ}; 145^{\circ}; 87^{\circ}; \text{ and } 62^{\circ}$

Corresponding transmission, in calories $\dots \dots \dots 2320; 1604; 782; \text{ and } 507.$

Of the quantity of heat produced by the preliminary heating and combustion of the fuel there has been absorbed :

Kils.		Calories.
1.465	coke, for the preparation	$2000 \times 1.465 \times 0.331497 = 971,$
2.381	ores $\dots \dots \dots$	$1100 \times 2.381 \times 0.214705 = 562,$
0.824	limestone $\dots \dots \dots$	$800 \times 0.824 \times 0.664293 = 250,$
1.000	pig-iron, as latent heat	$1 \times 139 \dots \dots = 139,$
2.205	slag $\dots \dots \dots$	$2.205 \times 60 \dots \dots = 132,$
0.044	water $\dots \dots \dots$	$0.044 \times 636.67 \dots \dots = 23,$
0.461	lime, as latent heat $\dots \dots \dots$	$0.461 \times 110 \dots \dots = 50,$
		<hr/> 2127;

The gases, however, do not leave the furnace at a temperature of 0° , but with a temperature of about 100° , and the consumption of heat is, therefore, increased by the heat which remains at this temperature in the gases. The specific heat of these gases is :

Kils.			
3·111 carbonic oxide	..	×	0·2497 = 0·77123
5·852 nitrogen	.. ..	×	0·2140 = 1·42790
0·363 C O ² from the lime		×	0·2164 = 0·07855
0·044 water	.. ..	×	0·475 = 0·02090

$$\underline{2·29858} \times 100 = 230 \text{ cal.}$$

which added to the 2127 calories above given, makes a total of 2357 calories.

The heat lost by transmission is thus :

$$4704 - 2357 = 2347 \text{ calories,}$$

which are distributed in the following manner over the four zones of the furnace according to the values previously obtained :

$$\left. \begin{array}{l} 5213 : 2320 = 2347 : x = \text{zone of gasification} = 1044 \text{ cal.} \\ 5213 : 1604 = 2347 : x = \text{fusion} = 722 \text{ " } \\ 5213 : 782 = 2317 : x = \text{reduction} = 325 \text{ " } \\ 5213 : 507 = 2347 : x = \text{preparation} = 229 \text{ " } \end{array} \right\} = 2347 \text{ cal.}$$

The final temperature of the zone of gasification will be :

$$= \frac{4704 - 1044}{2·19913} = 1664^{\circ} \text{ C.}$$

The limits of temperature of the zone of fusion are, therefore, 1664° and 800°, whence the absorption of heat in that zone will be :

By the preparatory heating, from

Degrees.	Calories.
800 to 1664 = 1·465 kil. coke	× 864 × 0·379927 = 481
800 " 1100 = 1 " iron	× 300 × 0·149691 = 45
800 " 1300 = 2·205 " slag	× 500 × 0·265393 = 292
By transmission	= 722
By heat rendered latent by the melting of the iron	1 kil. × 139 = 139
By heat rendered latent during the melting of the slag	2·205 kils. × 60 = 132
	993 "

The absorption of heat in the zone of reduction is :

By the preparatory heating, from

Degrees.	Calories.
500 to 800 = 1·465 kil. coke	.. × 300 × 0·263693 = 116
500 " 800 = 2·381 " ores	.. × 300 × 0·224300 = 160
500 " 800 = 0·824 " limestone	× 300 × 0·557654 = 138
	414 "

By the decomposition of the lime-
 stone } $0.461 \text{ kil.} \times 110 = 50$ } 402 calories.
 By transmission } $= 352$ }

The absorption of heat in the zone of reduction is :

By the preparatory heating, from

Degrees.		Calories.	
0 to 500 = 1.456 kil. coke ..	$\times 500 \times 0.186197 =$	136	} 469 "
0 ,, 500 = 2.381 ,, ores ..	$\times 500 \times 0.185420 =$	221	
0 ,, 500 = 0.824 ,, limestone	$\times 500 \times 0.273284 =$	112	
By transmission		= 229	} 482 "
Latent heat of 0.044 kil. of water	$\times 536.67..$	= 23	
Heat in waste gases, as above ..		= 230	

We have seen from Ebelmen's observations that the absorption of latent heat in the furnace naturally produces a sudden decrease of the temperature, and does not require any space in the furnace. It follows, therefore, that the capacity of the shaft must be apportioned to the several zones in a manner very nearly proportional to the quantities of heat required for the preparatory heatings.

But the total volume of the shaft is = 113.806 cubic mètres, the total quantity of heat absorbed by the preliminary heating of the materials = 1701 calories, and the volumes of the zones are therefore as follows :

			Cubic mètres.
Zone of fusion	1701 : 818 =	$113.806 : x = 54.7$	} 113.8
,, reduction	1701 : 414 =	$113.806 : x = 27.7$	
,, preparation	1701 : 469 =	$113.806 : x = 31.4$	

We obtain by this method not only results which are very near the truth, but we also obtain the means of determining the modifications which are produced by a change in the quantity of the fuel in the charges, in the material of the slags, by the hot blast, &c., &c., as we shall hereafter demonstrate.

CHAPTER XXVI.

AUXILIARY MEANS FOR CALCULATING THE TRANSMISSION OF THE WALLS OF THE BLAST-FURNACE.

We have frequently mentioned the formula :

$$t' = \frac{t - t''}{1 + Q \frac{e}{C}} + t'' \text{ where } Q = \frac{S m a''' (a' - 1) + L n t'}{t};$$

and in the following Table are given the values of Q , and their logarithms for temperatures of the surface of the furnace, varying between 10° and 571° . We may take $\frac{e}{C} = 1$, for only proportional numbers are required for the determination of the transmission. The temperature of the air, $= t''$, is taken in this Table as 20° ; if, therefore, the average temperature of the inner wall of the furnace is $t = 500^\circ$, we should get :

$$t' = \frac{500 - 20}{1 + Q} + 20 = \frac{480}{1 + 8.4647} + 20 = 71^\circ,$$

and the quantity of heat transmitted in the unit of time per unit of surface is then :

$$Q t' = 71 \times 8.4647 = 601 \text{ calories.}$$

t' .	Q .	log. Q .	t' .	Q .	log. Q .	t' .	Q .	log. Q .
10	6.1533	0.78911	22	6.7533	0.82952	34	7.2214	0.85862
11	6.2140	0.79337	23	6.7955	0.83222	35	7.2565	0.86073
12	6.2716	0.79738	24	6.8367	0.83485	36	7.2934	0.86293
13	6.3273	0.80122	25	6.8866	0.83808	37	7.3290	0.86504
14	6.3803	0.80484	26	6.9178	0.83997	38	7.3634	0.86708
15	6.4321	0.80835	27	6.9573	0.84244	39	7.4000	0.86923
16	6.4817	0.81169	28	6.9960	0.84485	40	7.4348	0.87127
17	6.5297	0.81489	29	7.0348	0.84725	41	7.4695	0.87329
18	6.5766	0.81800	30	7.0728	0.84959	42	7.5041	0.87530
19	6.6221	0.82100	31	7.1105	0.85190	43	7.5384	0.87728
20	6.6667	0.82391	32	7.1478	0.85417	44	7.5727	0.87925
21	6.7106	0.82676	33	7.1847	0.85641	45	7.6129	0.88155

TABLE—continued.

t.	Q.	log. Q.	t.	Q.	log. Q.	t.	Q.	log. Q.
46	7·6466	0·88347	86	8·9553	0·95208	126	10·341	1·01457
47	7·6803	0·88538	87	8·9875	0·95364	127	10·378	1·01611
48	7·7151	0·88734	88	9·0207	0·95524	128	10·414	1·01762
49	7·7475	0·88916	89	9·0546	0·95687	129	10·450	1·01910
50	7·7800	0·89098	90	9·0876	0·95845	130	10·485	1·02055
51	7·8039	0·89231	91	9·1212	0·96005	131	10·526	1·02227
52	7·8462	0·89466	92	9·1555	0·96168	132	10·561	1·02369
53	7·8679	0·89586	93	9·1878	0·96321	133	10·594	1·02506
54	7·9075	0·89804	94	9·2213	0·96479	134	10·634	1·02671
55	7·9455	0·90012	95	9·2544	0·96635	135	10·674	1·02833
56	7·9642	0·90114	96	9·2886	0·96795	136	10·713	1·02993
57	8·0000	0·90309	97	9·3218	0·96950	137	10·752	1·03148
58	8·0343	0·90495	98	9·3553	0·97106	138	10·790	1·03301
59	8·0677	0·90675	99	9·3894	0·97264	139	10·827	1·03452
60	8·0999	0·90848	100	9·4237	0·97422	140	10·864	1·03600
61	8·1311	0·91015	101	9·4574	0·97577	141	10·901	1·03745
62	8·1794	0·91272	102	9·4914	0·97733	142	10·944	1·03917
63	8·2063	0·91415	103	9·5258	0·97890	143	10·979	1·04057
64	8·2344	0·91563	104	9·5614	0·98052	144	11·021	1·04221
65	8·2770	0·91787	105	9·5942	0·98201	145	11·062	1·04383
66	8·3031	0·91924	106	9·6284	0·98355	146	11·096	1·04516
67	8·3284	0·92056	107	9·6627	0·98510	147	11·136	1·04674
68	8·3676	0·92260	108	9·6982	0·98669	148	11·176	1·04827
69	8·3913	0·92383	109	9·7317	0·98819	149	11·221	1·05005
70	8·4285	0·92575	110	9·7674	0·98978	150	11·260	1·05153
71	8·4647	0·92761	111	9·8005	0·99125	151	11·298	1·05301
72	8·5000	0·92942	112	9·8342	0·99274	152	11·336	1·05444
73	8·5470	0·93186	113	9·8712	0·99437	153	11·365	1·05586
74	8·5540	0·93217	114	9·9065	0·99592	154	11·422	1·05774
75	8·5866	0·93382	115	9·9431	0·99752	155	11·458	1·05911
76	8·6316	0·93609	116	9·9784	0·99906	156	11·500	1·06070
77	8·6622	0·93763	117	10·014	1·00062	157	11·541	1·06226
78	8·6924	0·93914	118	10·050	1·00214	158	11·582	1·06380
79	8·7217	0·94060	119	10·085	1·00368	159	11·623	1·06531
80	8·7573	0·94237	120	10·130	1·00559	160	11·669	1·06702
81	8·7904	0·94401	121	10·157	1·00677	161	11·708	1·06849
82	8·8273	0·94583	122	10·197	1·00846	162	11·759	1·07038
83	8·8560	0·94724	123	10·228	1·00978	163	11·791	1·07156
84	8·8889	0·94885	124	10·266	1·01140	164	11·835	1·07318
85	8·9222	0·95047	125	10·304	1·01300	165	11·879	1·07477

TABLE—continued.

<i>t</i> .	<i>Q</i> .	log. <i>Q</i> .	<i>t</i> .	<i>Q</i> .	log. <i>Q</i> .	<i>t</i> .	<i>Q</i> .	log. <i>Q</i> .
166	11·909	1·07580	206	13·786	1·13944	246	16·084	1·20639
167	11·964	1·07788	207	13·832	1·14151	247	16·147	1·20810
168	12·006	1·07939	208	13·904	1·14314	248	16·211	1·20981
169	12·048	1·08090	209	13·956	1·14476	249	16·275	1·21152
170	12·094	1·08257	210	14·013	1·14653	250	16·340	1·21325
171	12·135	1·08403	211	14·061	1·14803	251	16·402	1·21491
172	12·180	1·08565	212	14·113	1·14962	252	16·469	1·21665
173	12·226	1·08727	213	14·171	1·15139	253	16·534	1·21837
174	12·270	1·08885	214	14·218	1·15283	254	16·599	1·22007
175	12·314	1·09040	215	14·275	1·15458	255	16·667	1·22185
176	12·358	1·09195	216	14·329	1·15621	256	16·731	1·22351
177	12·401	1·09346	217	14·383	1·15785	257	16·798	1·22525
178	12·449	1·09515	218	14·461	1·16019	258	16·868	1·22707
179	12·492	1·09662	219	14·495	1·16122	259	16·934	1·22877
180	12·539	1·09826	220	14·548	1·16280	260	17·000	1·23045
181	12·585	1·09987	221	14·606	1·16436	261	17·069	1·23221
182	12·632	1·10147	222	14·659	1·16610	262	17·137	1·23394
183	12·678	1·10304	223	14·715	1·16777	263	17·206	1·23567
184	12·723	1·10458	224	14·774	1·16950	264	17·277	1·23746
185	12·768	1·10611	225	14·828	1·17107	265	17·347	1·23923
186	12·823	1·10798	226	14·891	1·17292	266	17·414	1·24089
187	12·866	1·10945	227	14·929	1·17403	267	17·487	1·24271
188	12·910	1·11091	228	14·997	1·17599	268	17·560	1·24452
189	12·958	1·11253	229	15·056	1·17772	269	17·628	1·24621
190	13·005	1·11412	230	15·114	1·17939	270	17·701	1·24800
191	13·052	1·11569	231	15·173	1·18106	271	17·773	1·24973
192	13·104	1·11741	232	15·234	1·18280	272	17·845	1·25151
193	13·150	1·11894	233	15·290	1·18441	273	17·920	1·25334
194	13·201	1·12061	234	15·350	1·18609	274	17·990	1·25504
195	13·246	1·12209	235	15·409	1·18777	275	18·064	1·25680
196	13·317	1·12439	236	15·469	1·18945	276	18·138	1·25859
197	13·345	1·12533	237	15·529	1·19113	277	18·212	1·26036
198	13·394	1·12691	238	15·589	1·19282	278	18·288	1·26216
199	13·447	1·12863	239	15·650	1·19451	279	18·362	1·26392
200	13·495	1·13018	240	15·711	1·19620	280	18·438	1·26572
201	13·545	1·13179	241	15·772	1·19789	281	18·511	1·26743
202	13·596	1·13342	242	15·835	1·19962	282	18·590	1·26928
203	13·647	1·13505	243	15·896	1·20128	283	18·667	1·27108
204	13·701	1·13675	244	15·958	1·20299	284	18·744	1·27286
205	13·749	1·13827	245	16·020	1·20467	285	18·820	1·27463

TABLE—continued.

t.	Q.	log. Q.	t.	Q.	log. Q.	t.	Q.	log. Q.
286	18·915	1·27680	326	22·428	1·35079	366	26·803	1·42819
287	18·979	1·27828	327	22·509	1·35235	367	26·926	1·43017
288	19·058	1·28008	328	22·608	1·35426	368	27·065	1·43240
289	19·136	1·28186	329	22·708	1·35518	369	27·198	1·43454
290	19·218	1·28370	330	22·803	1·35800	370	27·323	1·43653
291	19·296	1·28547	331	22·907	1·35997	371	27·450	1·43855
292	19·378	1·28731	332	23·011	1·36193	372	27·568	1·44056
293	19·459	1·28912	333	23·113	1·36385	373	27·772	1·44360
294	19·542	1·29096	334	23·215	1·36576	374	27·836	1·44460
295	19·624	1·29278	335	23·316	1·36766	375	27·967	1·44664
296	19·706	1·29460	336	23·420	1·36958	376	28·095	1·44863
297	19·789	1·29643	337	23·525	1·37153	377	28·231	1·45073
298	19·872	1·29825	338	23·629	1·37345	378	28·360	1·45270
299	19·966	1·30027	339	23·735	1·37539	379	28·495	1·45477
300	20·040	1·30190	340	23·840	1·37730	380	28·627	1·45678
301	20·126	1·30375	341	23·948	1·37926	381	28·763	1·45883
302	20·211	1·30559	342	24·054	1·38118	382	28·897	1·46086
303	20·333	1·30821	343	24·163	1·38315	383	29·034	1·46291
304	20·384	1·30928	344	24·272	1·38510	384	29·170	1·46493
305	20·470	1·31112	345	24·380	1·38703	385	29·308	1·46698
306	20·558	1·31298	346	24·507	1·38929	386	29·447	1·46904
307	20·645	1·31481	347	24·600	1·39093	387	29·580	1·47100
308	20·732	1·31665	348	24·711	1·39289	388	29·728	1·47316
309	20·821	1·31851	349	24·823	1·39485	389	29·869	1·47522
310	20·911	1·32037	350	24·935	1·39681	390	30·014	1·47733
311	21·001	1·32224	351	25·035	1·39855	391	30·160	1·47943
312	21·093	1·32413	352	25·162	1·40075	392	30·304	1·48150
313	21·184	1·32601	353	25·289	1·40293	393	30·449	1·48357
314	21·276	1·32788	354	25·397	1·40479	394	30·594	1·48564
315	21·377	1·32994	355	25·507	1·40666	395	30·741	1·48772
316	21·458	1·33158	356	25·629	1·40873	396	30·887	1·48977
317	21·544	1·33332	357	25·739	1·41059	397	31·037	1·49188
318	21·615	1·33535	358	25·857	1·41258	398	31·124	1·49310
319	21·739	1·33723	359	25·974	1·41456	399	31·334	1·49601
320	21·834	1·33913	360	26·096	1·41657	400	31·484	1·49809
321	21·928	1·34099	361	26·214	1·41854	401	31·631	1·50011
322	22·023	1·34287	362	26·333	1·42050	402	31·783	1·50219
323	22·121	1·34480	363	26·434	1·42217	403	31·938	1·50430
324	22·216	1·34666	364	26·555	1·42415	404	32·090	1·50637
325	22·313	1·34855	365	26·678	1·42616	405	32·236	1·50861

TABLE—continued.

Q.	log. Q.	t'.	Q.	log. Q.	t'.	Q.	log. Q.
32·403	1·51058	446	39·496	1·59655	486	48·552	1·68621
32·560	1·51268	447	39·705	1·59884	487	48·807	1·68848
32·718	1·51479	448	39·900	1·60097	488	49·064	1·69076
32·875	1·51686	449	40·100	1·60314	489	49·333	1·69314
33·038	1·51901	450	40·296	1·60526	490	49·586	1·69536
33·199	1·52112	451	40·511	1·60757	491	49·847	1·69764
33·359	1·52321	452	40·708	1·60968	492	50·114	1·69996
33·524	1·52535	453	40·931	1·61205	493	50·380	1·70226
33·685	1·52744	454	41·132	1·61418	494	50·648	1·70456
33·853	1·52960	455	41·343	1·61640	495	50·918	1·70687
34·019	1·53172	456	41·555	1·61862	496	51·187	1·70916
34·175	1·53369	457	41·764	1·62080	497	51·461	1·71148
34·352	1·53595	458	41·983	1·62307	498	51·732	1·71376
34·523	1·53811	459	42·109	1·62437	499	52·010	1·71609
34·682	1·54010	460	42·412	1·62749	500	52·288	1·71840
34·863	1·54237	461	42·633	1·62975	501	52·659	1·72073
35·036	1·54451	462	42·853	1·63198	502	52·852	1·72305
35·209	1·54665	463	43·077	1·63425	503	53·136	1·72539
35·383	1·54879	464	43·297	1·63646	504	53·422	1·72772
35·558	1·55094	465	43·520	1·63869	505	53·711	1·73006
35·725	1·55297	466	43·745	1·64093	506	54·000	1·73239
35·910	1·55521	467	43·957	1·64303	507	54·293	1·73474
36·081	1·55728	468	44·201	1·64543	508	54·595	1·73715
36·249	1·55929	469	44·428	1·64766	509	54·915	1·73961
36·451	1·56171	470	44·683	1·65014	510	55·241	1·74226
36·631	1·56385	471	44·891	1·65216	511	55·477	1·74411
36·817	1·56605	472	45·125	1·65442	512	55·778	1·74646
37·000	1·56820	473	45·323	1·65632	513	56·080	1·74881
37·175	1·57025	474	45·596	1·65893	514	56·386	1·75117
37·370	1·57252	475	45·836	1·66121	515	56·695	1·75354
37·560	1·57473	476	46·077	1·66348	516	57·000	1·75587
37·749	1·57690	477	46·314	1·66571	517	57·323	1·75825
37·936	1·57905	478	46·559	1·66800	518	57·624	1·76060
38·116	1·58111	479	46·802	1·67026	519	57·929	1·76297
38·407	1·58441	480	47·046	1·67252	520	58·256	1·76534
38·513	1·58560	481	47·296	1·67482	521	58·572	1·76769
38·706	1·58778	482	47·542	1·67708	522	58·893	1·77006
38·879	1·58971	483	47·794	1·67937	523	59·227	1·77244
39·178	1·59304	484	48·044	1·68184	524	59·542	1·77482
39·293	1·59431	485	48·297	1·68392	525	59·869	1·77720

TABLE—continued.

t'	Q.	log. Q.	t''	Q.	log. Q.	t'	Q.	
526	60·198	1·77958	541	65·386	1·81548	556	71·034	1
527	60·529	1·78196	542	65·743	1·81785	557	71·485	1
528	60·730	1·78340	543	66·111	1·82027	558	71·884	1
529	61·196	1·78672	544	66·430	1·82269	559	72·291	1
530	61·532	1·78910	545	66·852	1·82511	560	72·696	1
531	61·873	1·79150	546	67·224	1·82752	561	73·107	1
532	62·215	1·79389	547	67·599	1·82994	562	73·521	1
533	62·556	1·79627	548	67·975	1·83235	563	73·935	1
534	62·900	1·79865	549	68·355	1·83477	564	74·352	1
535	63·249	1·80105	550	68·739	1·83720	565	74·773	1
536	63·599	1·80345	551	69·372	1·84119	566	75·197	1
537	63·952	1·80585	552	69·501	1·84199	567	75·621	1
538	64·308	1·80826	553	69·901	1·84448	568	76·051	1
539	64·664	1·81066	554	70·293	1·84691	569	76·483	1
540	65·034	1·81314	555	70·687	1·84934	570	76·919	1
						571	77·352	1

The values of t' and t'' being thus known, the corresponding values of Q can be obtained by inspection.

CHAPTER XXVII.

TIME OCCUPIED BY THE CHARGES IN PASSING THROUGH THE SHAFT OF THE BLAST-FURNACE.

THE determination of the volumes of the zones made in Chapter XXV. is in itself already valuable, for it shows what space is occupied in the furnace by the different operations; but this determination also shows, at the same time, the periods which the different operations require in different methods of working the blast-furnace.

The blast-furnace at Seraing produces every day 8500

of white forge pig. The volumes of the charges are :

Ores	$\frac{1300}{2600} = 0.5$	cubic mètre	} 2.875 cubic mètres.*
Limestone	$\frac{450}{1200} = 0.375$	„	
Coke.. ..	$\frac{800}{400} = 2.0$	„	

The shaft thus contains $\frac{113.806}{2.875} = 39$ charges; and as one charge produces 546 kils. of pig-iron, the furnace thus contains $39 \times 546 = 21294$ kils. of pig-iron. The quantity of pig-iron that passes through per hour is $= \frac{8500}{12} = 708$ kils., and consequently the time necessary for the passing through of the total quantity of the charges $= \frac{21294}{708} = 30$ hours; thus the volume of materials charged per hour $\frac{113.806}{30} = 3.7935$ cubic mètres.

We thus find that the materials require (see Chapter XXV.)

$$\frac{54.7 \text{ m}^3 \cdot \text{hrs. mins.}}{3.7935} = 14 \quad 35, \text{ in order to pass through the zone of fusion.}$$

$$\frac{27.7 \text{ m}^3}{3.7935} = 7 \quad 18, \quad \text{„} \quad \text{„} \quad \text{reduction.}$$

$$\frac{31.4 \text{ m}^3}{3.7935} = 8 \quad 15, \quad \text{„} \quad \text{„} \quad \text{preparation.}$$

The time required for the passage through the zone of reduction is especially of great importance, for the reduction of the ores will be the more complete the longer the time, and *vice versa*.

The time of reduction, a little over seven hours and a quarter, is short, because half of the ores consist of finery slags, which cannot be reduced by carbonic oxide, but only by solid carbon.

* There are ores which have their volume reduced when heated (by loss of fluid matters, contents of argillaceous earth, &c., &c.) to one-third of the original volume. If such ores are used, this diminution has to be taken into consideration.

The analysis of the gases of this furnace is as follows:

$$\begin{array}{rcl}
 \text{Vol. } 11.39 \text{ CO}^2 & = & \text{vol. } 5.695 \text{ carbon} \\
 \text{,, } 28.61 \text{ CO} & = & \text{,, } 14.305 \text{ ,,} \\
 \text{,, } 57.06 \text{ N} & = & \text{,, } \text{---} \\
 & & \hline
 \text{Vol. } .. & & 21.000 \text{ carbon.}
 \end{array}$$

This shows that there is a great quantity of carbon in excess.

The composition of the gases, as we have calculated, without modification on this account, is:

$$\begin{array}{rcl}
 3.111 \text{ CO} & = & \text{vol. } 2.4859 = \text{vol. } 1.24295 \text{ C,} \\
 0.363 \text{ CO}^2 & = & \text{,, } 0.18458 = \text{,, } 0.09229 \text{ C,} \\
 5.852 \text{ N} & = & \text{,, } 4.6572 \text{ ---} \\
 & & \hline
 \text{Vol. } .. & & 1.33524 \text{ C,}
 \end{array}$$

which gives the proportions $4.6572 \text{ N} : 1.33524 \text{ C} = 1 : 0.2867$, whilst the analysis gave $57.06 \text{ N} : 21 \text{ C} = 1 : 0.3680$.

We have introduced into the calculation 1.333 kil. of carbon as producing heat, whilst the analysis of the gases shows that scarcely 1 kil. is really consumed by the blast. The production of heat in this furnace is therefore in reality $\{(0.5 \times 8000) - (0.5 \times 2400)\} - (0.333 \times 2400) + 971 = 2972$ calories, instead of 4704 calories (see Chapter XXV.). But this alters all the results.

The quantity 0.333×2400 is the heat of combination, which the carbon absorbs when it is converted into carbonic oxide by coming in contact with the protoxide of iron.

We leave it to the reader to make the calculation according to this base, for it is at present not our intention to give results, but only to give the method by means of which those results may be obtained.

CHAPTER XXVIII.

QUANTITY OF IRON CONTAINED IN THE CHARGES.

It is generally known that ores very rich in iron cannot be smelted without the addition of a great quantity of slag-forming material, this addition consisting partly of ores of inferior quality and partly of mixtures containing much carbonate of lime. The chemical composition of the slags thus produced has to be taken into consideration, in order to make them as basic as possible. It is not my intention to examine more minutely here whether this consideration is of any value, but it is certain that the quantity of the fluxes used has a greater influence upon the results obtained with a blast-furnace, and on the quality of the product, than the composition of the slags themselves. A proof of this is to be found in the fact that, in some iron-works in the south-western districts of England, where limestone cannot be easily obtained, there is substituted for this material, without any disadvantage, old blast-furnace slags.

The endless experiments and discussions on the chemical conditions of slags appear to have blinded metallurgists to the most important duty which the slags fulfil in the blast-furnace by absorbing heat, so as to moderate the temperature to that degree at which the reducing gases can act, thus also increasing the time occupied by the materials in passing through the zone of reduction.

In 1862, Messrs. Boulanger and Dulait took out a patent in Belgium for a method of smelting ores which contain more than 35 per cent. of iron. This "egg of Columbus" consisted simply in reducing the proportion of coke in the charges. Their reasoning was as follows:—1 kil. of pig-iron contains, when it arrives in a molten state at the hearth, w calories; and 1 kil. of slag, w' calories. Ores which contain 25 per cent. of iron and 75 per cent. slags thus require $\frac{1}{4}w + \frac{3}{4}w'$ calories per kil., whilst ores with 50 per cent. of iron consume only $\frac{1}{2}w + \frac{1}{2}w'$ calories, whence the saving for 1 kil. of iron is in the latter case $2w'$. The usual practice however, contrary to this simple reasoning, has been to

use an increased instead of a reduced proportion of coke in the charges, when ores containing more than 40 per cent. of iron had to be smelted; and the temperature was thus increased to such a degree, that the oxide of iron could no longer be reduced by the gases, for it was soon absorbed by the slags. According to Messrs. Boulanger and Dulait's calculation 1 kil. of finery pig-iron obtained from ores containing 25 per cent. of iron requires 1.69 kil. of coke, whilst this consumption is reduced to 0.54 kil. for ores containing 50 per cent.; foundry pig-iron from ores containing 25 per cent. requires 2.23 kils. of coke, while 0.66 kil. is necessary in the case of ores containing 50 per cent.

After stating these facts, MM. Boulanger and Dulait admit that a diminution in the proportion of fuel in the charges must necessarily produce a decrease in the amount of the reducing gases, and that the process of reduction in the shaft may therefore be retarded. But the time allowed is an element which has to be taken into consideration, and it may thus be possible that the consumption required for rich ores may be larger than that obtained as a result of their calculation. In other words, the inventors may have "counted their chickens before they are hatched."

In oxide of iron 25 parts iron are combined with 10.7 parts of oxygen, or 50 iron with 21.4 oxygen, which latter must be absorbed by the carbonic oxide existing in the gases, in order that metallic iron may be obtained. It is necessary, therefore, as practice has shown, to increase the quantity of the fuel, in order to produce a quantity of gas which is sufficient to absorb the larger quantity of oxygen.

But this practical opinion, correct in itself, is just as premature as that of the inventors above named; for the augmentation of the fuel increases the temperature of the shaft to such a degree that the reduction of the ores by means of carbonic oxide is suspended.

The following prize question put forward by the *Ancien élèves de l'Ecole de Liège* gave rise to the illusionary invention of Messrs. Boulanger and Dulait:

"The treatment of oolitic ores; statement of the causes which prevent their application in larger proportions than are usual at the present time, and statement of the proposed improvements, for enabling them to be more largely employed."

The causes which prevent such ores from being largely used have already been given, and the means by which these obstacles may be overcome are the simplest in the world; it is sufficient to construct the hearth of the furnace in such a manner, that the excess of heat produced in that part is transmitted through the walls. If the iron manufacture requires any improvement, it is certainly that of decreasing the enormous production of slags. M. Léon Fromont, a Belgian mining engineer, has calculated that the transportation of the slags of a single blast-furnace costs 30 francs daily, or 11,000 francs yearly; that the land upon which the slags have to be stored up has to be bought besides; and, finally, that the manufacturing district of Chatelet alone has covered with slags during the last thirty years 20 hectares (49·4 acres) of land, which cannot, therefore, be used for agricultural purposes.

As the zone of reduction, however, is not enlarged by the cooling of the gases, the time for passing through that zone is not increased in proportion to the larger contents of iron, and the plan of cooling the hearth alone is, therefore, not sufficient to enable the proportion of iron in the charges to be increased at will; we shall, however, hereafter describe and discuss means which will enable this to be done.

CHAPTER XXIX.

CARBURIZATION OF THE IRON.

My experiments on reduction have shown that the carburization of the iron begins during its reduction; but of course the carburization ceases as soon as the iron is surrounded by soft and half-molten slags. This continues to be the case until the

iron itself is molten, for it then falls in drops into the hearth, penetrates the layer of slags which the hearth contains, and accumulates upon the bottom of the latter. It is, therefore, almost impossible that the iron can receive carbon from any other source than the carbonic oxide or at any other place than in the zone of reduction. This will be more clearly understood if we calculate the volumes of the zones of a furnace employed for the production of foundry and finery iron. Such a furnace is that of Mägdelsprung, in which the same ores, only differently mixed, are melted for the production of both these kinds of pig-iron.

The charges contain 63 per cent. of spathic iron ore, which contains 38 per cent. of carbonic acid.

For the production of 1 kil. of foundry iron, there are used : 3·76 kils. of ores = 1 kil. of iron, and 2·76 kils. of other matters, which pass with the iron through the furnace, until the carbonic acid (= 0·944 kil.) is separated. This separation does not take place until a temperature of 800° is reached, and up to that time the quantity of slag is, therefore, 2·76 kils. per 1 kil. of iron. After the carbonic acid has been disengaged $3·76 - (1 + ·944) = 1·816$ kil. of slags have to be taken into account per 1 kil. of iron ; but to that quantity, however, has to be added 0·134 kil. of slags due to the 0·240 kil. of limestone per 1 kil. of iron, which is used as a flux.

Finally, there is used per kil. of pig-iron 1·56 kil. of charcoal, which is reduced, however, by moisture and other fluid matters amounting to 12 per cent., leaving 88 per cent., or 1·373 kil. of carbon :

$$\begin{array}{rcl}
 1·373 \text{ carbon gives} & \dots & \frac{1·373}{2} \times 8000 = 5492 \text{ Calories.} \\
 \text{less} & \dots & \frac{1·373}{2} \times 2400 = 1592 \\
 & & \hline
 & & = 3900 \\
 \text{plus for preliminary heating} & & \\
 \text{of the carbon } 1900 \times 1·373 \times 0·28827 = 752 & & \\
 \text{" blast } 250 \times 7·858 \times 0·2377 = 467 & & \\
 & & \hline
 & & = 1119 \\
 & & \hline
 & & = 5019.
 \end{array}$$

The specific heat of the products of combustion is :

$$\left. \begin{array}{l} 3.204 \text{ kils. of carbonic oxide} \times 0.2479 = 0.79426 \\ 6.027 \text{ ,, nitrogen} \times 0.244 = 1.47060 \end{array} \right\} = 2.26486;$$

whence the temperature at the limit of the zone of gasification is

$$\frac{5019}{2.26486} = 2216^{\circ} \text{ C.,}$$

but this temperature is diminished by the transmission.

If we take this limit = 1600° , the mean temperature of the zone of fusion = $\frac{1600 + 1000}{2} = 1300^{\circ}$, that of the zone of

reduction = $\frac{1000 + 500}{2} = 750$, and that of the zone of prepara-

tion = $\frac{500}{2} = 250^{\circ}$, and we thus get for :

				Calories.
zone of gasification	$t' = 149^{\circ}$	and the transmission	$t' Q = 1672$	
„ fusion	$t' = 131^{\circ}$	„ „	$t' Q = 1379$	} 4024.
„ reduction	$t' = 72^{\circ}$	„ „	$t' Q = 612$	
„ preparation	$t' = 47^{\circ}$	„ „	$t' Q = 361$	

Now, the absorption of heat by the column of fusion is as follows :

		Kils.			Calories.
Preliminary heating of the fuel	1.56	from	0 to 1600	$\times 0.25968$	= 648
„ „ ores	3.76	„	0 „	1150×0.342541	= 1480
„ „ limestone	0.24	„	0 „	1150×0.664292	= 183
„ „ slags	1.95	„	1150 „	1300×0.284570	= 83
Latent heat	1 iron	.. ..	.. ..	.. ..	= 175
„	1.95 slags	$\times 60$	.. ..	.. ..	= 117
„ of the charges ..	0.20 water	$\times 536.67$	.. ..	.. ..	= 107
Heat of combination	1.020 CO^2	$\times 251$	.. ..	.. ..	= 256
Waste gases	3.204 CO	$\times 0.2479 \times 100$			
„	6.027 N	$\times 0.244 \times 100$			
„	1.020 CO^2	$\times 0.2164 \times 100$			
„	0.200 water	$\times 0.475 \times 100$			
					} .. = 258

3307

The transmission is, therefore, = $5019 - 3307 = 1712$ calo-

ries, and for the four zones, according to the calculation from the proportionate figures given above, we get:

	Calories	
The zone of gasification transmits	712	} as above, 1712.
That of fusion	587	
- reduction	261	
- preparation	152	

The final temperature of the zone of gasification is thus reduced to:

$$\frac{5019 - 712}{2 \cdot 26486} = 1902^{\circ} \text{C.}$$

We thus get the following quantities of heat in the different zones:

Zone of fusion: preliminary heating		Kils.	Calories.	
of the fuel	from 1000 to 1902°	$\times 1 \cdot 55$	$\times 0 \cdot 28827$	= 406
" ores	" 1000 " 1150°	$\times 1 \cdot 0$	$\times 0 \cdot 200482$	= 30
" slags	" 1000 " 1300°	$\times 1 \cdot 950$	$\times 0 \cdot 278317$	= 163
} = 599.				
Latent heat of the iron	"	1	$\times 175$	= 175
"	"	1 \cdot 95	$\times 60$	= 117
} = 879.				
transmission = 578				
Zone of reduction: preliminary heating				
of the fuel	from 500 to 1000°	$\times 1 \cdot 56$	$\times 0 \cdot 25838$	= 210
" ores	" 500 " 800°	$\times 3 \cdot 76$	$\times 0 \cdot 376925$	= 425
" limestone	" 500 " 800°	$\times 0 \cdot 24$	$\times 0 \cdot 675083$	= 48
" iron	" 800 " 1000°	$\times 1 \cdot 00$	$\times 0 \cdot 146516$	= 29
" slags	" 800 " 1000°	$\times 1 \cdot 95$	$\times 0 \cdot 247047$	= 96
} = 808.				
transmission = 261				
Heat of combination: CO^2	"	1 \cdot 02	$\times 251$	= 256
} = 517.				
Zone of preparation: preliminary heating				
of the fuel	from 0 to 500°	$\times 1 \cdot 56$	$\times 0 \cdot 24539$	= 191
" ores	" 0 " 500°	$\times 3 \cdot 76$	$\times 0 \cdot 193545$	= 364
" limestone	" 0 " 500°	$\times 0 \cdot 24$	$\times 0 \cdot 273285$	= 33
} = 588.				
Latent heat of the water	"	0 \cdot 2	$\times 536 \cdot 67$	= 107
Waste heat as above	"	"	"	= 258
} = 517.				
transmission = 152				

Now, the volumes of these zones are proportionate to the

quantities of heat absorbed for the preliminary heating. If the total volume of the materials = 26.55 cubic mètres, we get the volumes:

	Cubic Mètres.
For the zone of fusion	= 599 = 7.972
„ „ reduction	= 808 = 10.753
„ „ preparation	= 588 = 7.825
	<hr/>
	1995 = 26.550

If the furnace has, however, to produce forge iron, 2.632 kils. of ores and 0.158 kil. of limestone are required for each kil. of pig-iron, and the ores lose, at a temperature of 800°, 0.640 kil. of carbonic and the limestone 0.069 kil.

The consumption of charcoal, also, per kil. of pig-iron = 1.18 kil., this charcoal containing 88 per cent., or 1.034 kil. of carbon.

Heat produced	$\frac{1.034}{2} \times 8000$	Calories.	4136
less	$\frac{1.034}{2} \times 2400$		1241
			<hr/>
plus for preliminary heating	Kils.	2895	
of the fuel	$1.034 \times 0.26098 \times 1700$	= 469	} = 3716.
„ air	$5.918 \times 0.2377 \times 250$	= 352	

The specific heat of the products of combustion is:

Kils.	
2.412 carbonic oxide	$\times 0.2479 = 0.59817$
4.539 nitrogen	$\times 0.244 = 1.10750$
	} 1.70567,

whence the first value for the temperature $\frac{3716}{1.70567} = 2178^\circ \text{C.};$

and for the mean temperatures,

1500, the value of $t' = 144^\circ$	and $Q t' = 1587$	} 3893.
1250 „ $t' = 128^\circ$	„ $Q t' = 1333$	
750 „ $t' = 72^\circ$	„ $Q t' = 612$	
250 „ $t' = 47^\circ$	„ $Q t' = 361$	

The absorption of heat by the column of fusion is :

Preliminary heating: Kils.		Calories.
of the fuel	1.18 from 0 to 1500	$\times 0.25838 = 458$
" ores	2.632 " 0 "	$1050 \times 0.342541 = 947$
" limestone	0.069 " 0 "	$1050 \times 0.664293 = 48$
" slags	1.081 " 1050 "	$1300 \times 0.284570 = 76$
Latent heat of	1 forge pig ..	$\times 139 = 139$
" "	1.081 slags.. ..	$\times 60 = 65$
" "	0.15 water	$\times 536.67 = 80$
Heat of combination		
of	0.709 CO ²	$\times 251 = 178$
Heat carried off by the waste gases :		
Kils.		
2.413	$\times 0.2479$ CO	$= 0.59817$
4.539	$\times 0.244$ N	$= 1.10750$
0.150	$\times 0.475$ H O	$= 0.07125$
0.709	$\times 0.2164$ CO ²	$= 0.15342$
		$1.93034 \times 100 = 193$

Whence the transmission = $3716 - 2184 = 1533$ calories, divided between the various zones as follows :

Transmission of the zone of gasification	= 625
" " fusion	= 525
" " reduction	= 242
" " preparation	= 142
} = 1534.	

Final temperature of the zone of gasification :

$$\frac{3716 - 625}{1.70567} = 1812^{\circ} \text{C.}$$

Consumption of heat in the zone of gasification :

Preliminary heating: Kils.		Calories.
of the fuel	1.18 $\times (1812 - 800)$	$\times 0.389613 = 426$
" slags	1.081 $\times (1300 - 800)$	$\times 0.2658393 = 157$
" iron	1.00 $\times (1050 - 800)$	$\times 0.149691 = 37$
Latent heat of the iron	1 $\times 139$	$= 139$
" " slags	1.081 $\times 60$	$= 65$
		transmission = 525
		} = 729.

Consumption of heat in the zone of reduction :

Preliminary heating: Kils.		Calories.
of the fuel	1.18 $\times (800 - 500)$	$\times 0.263693 = 93$
" ores	2.632 $\times (800 - 500)$	$\times 0.198739 = 157$
" limestone	0.069 $\times (800 - 500)$	$\times 0.557654 = 11$
		} = 261.

Heat of combination

$$\left. \begin{array}{l} \text{of the carbonic acid} = 0.709 \times 251 \quad \dots \dots \dots = 178 \\ \text{transmission} = 242 \end{array} \right\} = 420.$$

Consumption of heat in the zone of preparation :

Preliminary heating :	Kils.	Calories.	
of the fuel	1.18	$\times 500 \times 0.24539$	$= 145$
" ores	2.632	$\times 500 \times 0.193545$	$= 254$
" limestone	0.069	$\times 500 \times 0.273285$	$= 9$
} = 408.			
Latent heat of the water	0.15	$\times 536.67$	$= 80$
Heat carried off, as above			$= 193$
} = 415.			
transmission = 142			

Volumes of the zones :

	Cubic Mètres.
Zone of fusion	620 = 12.77
" reduction	261 = 5.38
" preparation	408 = 8.40
	<hr/>
	1289 26.55

The volume of the zone of reduction in a furnace producing foundry iron is therefore 10.753 cubic mètres, whilst it is equal to but 5.38 cubic mètres in a furnace producing forge pig. In the former case 2250 kils. are produced in twenty-four hours; in the latter case 3100 kils.; and the times occupied by the ores in passing through the zone of reduction are therefore in the proportion of $10.753 : \left(\frac{2250}{3100} \times 5.38 \right) = 2.75 : 1$.

This proportion, however, is still further altered to 3.65 : 1, because the carbon required for 1 kil. of foundry iron is 1.373 kil., whilst that for 1 kil. of forge pig is only 1.034 kil.

For the production of spiegeleisen,* an iron which is fully saturated with carbon, the time occupied by the materials in

* There exist very different opinions as to the conditions requisite for the formation of spiegeleisen. It is proved by experiments that contact with carbonic oxide at the temperature of the zone of reduction is not sufficient to reduce all oxides of manganese to metallic manganese, but only to protoxide of manganese; and the latter must, therefore, pass into the slags, from which it is only removed by solid carbon; it passes then into the iron, and an excess of manganese existing, silicious acid is no longer reduced; this is perhaps the correct explanation of the process, all the iron having been already reduced when it arrives in the zone of fusion.

passing through the zone of reduction is still greater. The furnaces at Hirflau, in Styria, produce, for example, with a capacity of the shaft of 20 cubic mètres, only 1050 kils. in the twenty-four hours. The proportion between the capacity of this furnace and that previously considered is as 1 to 1·3, and thus to render the production in the two cases comparable we have to multiply by this proportion; thus, $1\cdot3 \times 1050 = 1365$ kils., whence the proportion between the times occupied by the materials in passing through the zone of reduction for spiegeleisen and for foundry iron respectively = $\frac{2250}{1365} = 1\cdot648$; that is to say, when

spiegeleisen is produced, the ores remain 1·648 times as long in contact with the reducing gases as is the case during the production of foundry iron. It has further to be considered that the spathic iron ores used for the production of spiegeleisen contain only protoxide of iron, which is necessarily more quickly reduced than oxide of iron.

The times occupied in passing through the zone of reduction for the three sorts of iron considered above are therefore :

Spiegeleisen	..	..	..	..	..	4·53
Foundry iron	..	..	..	..	..	2·75
Forge pig	..	..	..	..	..	1·00

These proportions show clearly that the carburization of the iron does not depend upon the extent of an imaginary zone of carburization, but upon the time during which the carbonic oxide and ores remain in effective contact—that is to say, at temperatures between 500 and 800°. The experiments with the reductometer (Chapter XXI.) have shown that this time can be reduced by the use of richer gases.

CHAPTER XXX.

FORM OF THE BLAST-FURNACE.

Of all the important points connected with a blast-furnace, none has been the subject of greater controversy amongst empirics, and none has presented more difficulties to theoretical men than the question as to what form should be given to the furnace itself; all opinions, however, coincide in one point, namely, that wide hearths are better for the production of forge pig, whilst narrower ones are better for foundry iron. Scheerer's explanation of this is that the products of combustion in a larger hearth meet the material which has to be melted with less velocity than in a narrower one; this explanation, however, cannot be admitted, for a greater quantity of the material to be melted is necessarily brought in contact with these products by a larger volume of hearth.

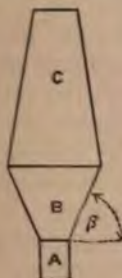
It is generally admitted that the wide hearth is especially of use for reducing the temperature, and that a reduced temperature is a necessary condition for the production of forge pig. That is, however, as we shall prove later, by no means the case, for the production of forge irons—that is to say, of pig-irons, poor in carbon, depends solely upon a complete reduction of the ores in the zone of reduction and upon the subsequent separation of the iron from slags containing protoxide by means of solid carbon.

The only true reason which makes the wider hearth more suitable for forge iron is perhaps that the slags containing iron and carbon can distribute themselves better over the more extended walls of the furnace, and that they thus arrive more slowly upon the hearth, and find even there a greater space, so that the action of the solid carbon upon the protoxide of iron has more time for its termination.

This opinion seems to be confirmed by the fact that the layer of slags above the hearth is always darker immediately after the slags have been tapped off, but it becomes lighter the longer it

remains exposed to the high temperature which exists at this point.

The usual form of the blast-furnace is represented by the annexed figure: A is the hearth; B are the boshes; and C the shaft or stack. The angle β is the angle of the boshes. Many metallurgists attribute great importance to this angle. Scheerer quotes K. A. Weniger, who states that the consumption of fuel for the angles of 25° , 45° , 55° , and 65° , varies in the proportions $1\frac{1}{8}$, $1\frac{1}{2}$, $2\frac{1}{4}$, and $3\frac{1}{4}$; and although this statement is not adopted by Scheerer, he, nevertheless, considers these numbers worthy of a certain consideration.



The less the walls of the boshes are inclined, the sooner the section of the column of fusion increases, and the resistance becomes so much less. If Weniger acted on the still general but entirely false supposition, that equal manometric pressures give equal quantities of air for equal sections of the tuyere holes, and if he applied for these different angles of the boshes equal pressures and tuyere holes of equal size, then, of course, he introduced more and more air in the unit of time, as the angle β decreased, and he thus increased the consumption of fuel in the unit of time, and consequently also the quantity of materials operated on. A saving of fuel was therefore finally obtained, for the quantity of heat transmitted through the walls of the furnace becomes, with slowly sinking charges, naturally more unfavourable in proportion to the quantity of pig-iron produced.

In this form of blast-furnace, therefore, the larger the angle of the boshes, the greater is the resistance of the column of fusion; and as a larger angle of the boshes involves a smaller section of the shaft, the resistance is thus increased considerably. Under these circumstances, the consumption of carbon in the unit of time, even with a high pressure of the blast, is not often very large, whence also the charges remain longer in the shaft and are more completely reduced, before half-molten slags make them impenetrable by the reducing gases. For this reason this

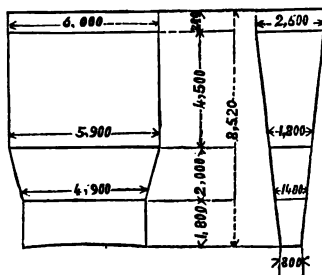
form of the furnace is said to produce the purest and best pig-iron. The reader will, however, easily understand that any other form may also produce good iron if the effective quantity of the blast is only regulated in such a manner that the charges remain for a sufficient time in the shaft, so that they become completely reduced before they arrive at a point at which the temperature exceeds 800°C .

This traditional form of the blast-furnace has therefore been abandoned for some years* in England, France, and Belgium, and the annexed form has, with more or less variation, been adopted. The dimensions of height and diameter have at the same time been increased in order to produce larger quantities, the proportionate transmission of heat being thus diminished; while, on the other hand, the pressure and temperature of the blast have been increased, the effect being a deterioration of the quality of the products. These combined means for obtaining a larger production are really the reasons for the inferior quality of the product—an inferiority for which the form of the furnace has itself been blamed.

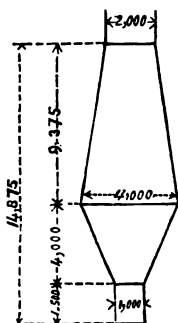
We shall show in Chapter XXXVI. that the high pressure of blast required for large and high furnaces involves heavy expenses without giving better results. It is for this reason that Raschette's furnace, shown in the annexed sketch, has the decided advantage over all former forms, in that it avoids all disadvantages of the high-pressure blast, and that the proportion between its capacity and the surface of its walls is not more unfavourable than in circular furnaces.

The annexed figure represents a circular furnace of the same

* This statement requires some qualification.—TRANSLATORS.



capacity as that on Raschette's system, above illustrated, but its height is 14·875 mètres, instead of 8·52 mètres. The former furnace has a capacity of 87 cubic mètres, and the surface of the walls amounts to 123·836 square mètres; the capacity of the latter furnace is 87 cubic mètres, and the surface of its walls 124·420 square mètres.



With respect to the transmitting surfaces of the walls, both furnaces are equal; but the greater height of the circular furnace and its smaller section must increase considerably the resistance of the column of fusion, and require therefore a much higher pressure of the blast.

The section of the hearth in Raschette's furnace is $4.9 \times 1.1 = 5.39$ square mètres; that of the circular furnace $= 1^2 \times \frac{\pi}{4} = 0.79$ square mètre, whence the proportion of the velocities for equal quantities of blast per unit of time is as 0.14 : 1, and the pressures of blast necessary in the two cases will be as 1 : 51.

The defenders of the old form say that the charges by sinking in a shaft which has the form of an inverted cone are more loosened by the gradually increasing section than they would be in a shaft of another form. I believe this to be perfectly true; but this loosening ceases to be necessary as soon as the velocity of the gases is reduced by an increased section; and if that is the case to such an extent as in Raschette's furnace, the gases will even penetrate the ores better than in narrow blast-furnaces, even with very conical shafts.

CHAPTER XXXI.

ANALYSIS OF THE GASES IN THE BLAST-FURNACE.

IN 1839 Bunsen and Ebelmen undertook, simultaneously and without knowledge of each other's operations, the analysis of the gases to be found at different depths in the shaft of a blast-furnace. For this purpose Bunsen employed the volumetric method, whilst Ebelmen made his analyses by weight, when, of course, the proportion of carburetted hydrogen contained in the gases escaped him. Although it is of no importance, as far as the practical application of these analyses go, whether CH^2 or only H is given in the result, the omission of the determination of CH^2 has nevertheless the great disadvantage, that the proportionate composition is altered; for 1 vol. CH^2 consists of 0.2 vol. C and 0.8 vol. H, which united pass into the calculation as 0.2 vol. CO and 1.6 vol. H; and the result gives thus 0.8 vol. H too much for each 1 vol. CH^2 .

But the analysis by weight so far deserves the preference, that it gives an average result of the gases which have passed through during a longer time; for of course these gases vary between two successive charges.

The following analysis of the waste gases of the blast-furnace at Bårum proves, however, that the volumetric method may also lead to important errors:

CO ²	vols. 22.20	} 100.00 vols.
CO	..	..	" 8.04
CH ²	..	..	" 3.87
H	..	..	" 1.46
N	..	..	" 64.43

These gases contain 15.894 vols. of carbon = 17.049 kils.

The kind of ores smelted is not given (although information on this point would be of the greatest importance in criticizing the result), but these ores can neither have contained carbonic acid, nor can carbonic acid have been added to the charges by

the additional material for the slags, for 64.43 per cent. of nitrogen correspond with 17.086 per cent. of carbon, which had to be volatilized by the blast. There is thus a deficit in the gases of 1.192 vol. per cent. of carbon. But each kilogramme of the iron produced requires but very seldom less than 1 kil. of carbon, and the 100 vols. of gas (a cubic mètre being taken as the unit of volume) correspond therefore with 17.049 kils. of iron, which when in the state of oxide were combined with 7.3067 kils. of oxygen = 5.1086 vols.

But the gases contain 26.22 vols. of oxygen, and there remain thus 21.1114 vols. of oxygen, which may originate from the blast; the 64.43 vols. of nitrogen existing in the gases, however, only correspond to 17.0663 vols. of oxygen. This analysis shows, therefore, an excess of oxygen of 4.0451 vols. (above 15 per cent.), which cannot be justified in any way.

A reduction of the ores by gases containing but 8 per cent. of carbonic oxide would be almost impossible, and if the reduction in the blast-furnace at Bärum had been effected by means of solid carbon, the gases should not have contained any carbonic acid.

After these remarks upon the modes of analysis and the means of checking them, we must put the question: What is the practical application of such analyses? No treatise on metallurgy gives any sufficient answer to this question. Scheerer, for example, although he has arranged the results of various analyses of blast-furnace gases according to the fuel used, and calculated their average value in fuel, has omitted to note that the composition of the gases does not depend so much upon the fuel used as upon the management of the furnace and the nature of the ores; and he further neglects to take into account the aqueous vapour contained in the gases.

Ebelmen, however, not only made analyses, but he was also anxious to draw conclusions from them. The analyses of gases taken from different depths in the furnace show that there is a point in every shaft where no carbonic acid exists, but absolutely only carbonic oxide, and that this point occupies a position more or less high above the tuyere holes, a fact that proves that no

carbonic oxide is transformed into carbonic acid when the iron has become surrounded by half-molten slags. We have already shown that the slags are brought into this state as soon as the charges have arrived at a temperature of between 800° and 1000° .

But a very short distance above the place where only carbonic oxide exists, a great quantity of carbonic acid is found, this being derived either from the carbonate of lime used as a flux, or from the ores themselves. As the gases rise the proportion of carbonic acid is constantly increased by the reduction which goes on, up to the throat of the furnace, where the proportion of carbonic oxide becomes again increased by the products of distillation of the fuel, as shown by Ebelen. These analyses enable us, therefore, to follow out the process of reduction, if, as is done in the case of some of Ebelen's investigations, the analyses of the materials contained in the charges are made.

Having an exact knowledge of the composition of the charges, it is thus possible to calculate from the analyses of the waste gases the amount of carbon which passes by direct reduction into the gases, and which was, therefore, not combined with the air introduced.

Finally, in order to check this last determination, a calculation can be made of the oxygen which has been separated from the oxides existing in the zone of reduction by means of carbonic oxide.

The charges of the blast-furnace at Clerval contained, per cent.:

Kils.									
Carbon	30·648	from the charcoal	..	..	..	..	..	..	} = 28·572 vols.
"	2·509	from the ores and the CO^2 Ca O	..	..	..	..	..	..
Oxygen	12·000	from the ores	..	..	..	..	..	..	} = 20·780 kils.
"	2·089	" carbon	..	..	..	..	..	..
"	6·691	" carbonic acid in the ores	..	..	..	..	..	..	} = 14·495 vols.
		and the limestone	..	..	..	..	..	..

If now all the carbon from the charcoal had been transformed into carbonic acid in the zone of gasification and had then been reduced to carbonic oxide, the gases should show an excess of

2·509 of carbon and 20·780 of oxygen, that is to say the proportion $\frac{14\cdot495}{2\cdot339} = 6\cdot197$. But the analysis gave:

12·88 vols. CO ²	=	6·440 vols. C	and	12·880 vols. O
23·51 „ CO	=	11·755 „		11·755 „
57·71 N		18·195 „		24·635 „

Or calculated for :

100 vols. N	=	31·485 vols. C	and	42·629 vols. O
		26·519 „		26·511 „
= excess of	4·966 „			16·118 „

This, however, does not give the proportion 6·197, but $\frac{16\cdot118}{4\cdot966} = 3\cdot246$, which shows that the excess of carbon contained in the gases is but about half as great as it should be, if a part of it was not combined directly with the oxygen in the ores. This excess is :

$$14\cdot495 : 16\cdot113 :: 2\cdot339 : x = 2\cdot601 \text{ vols. of carbon} = 2\cdot790 \text{ parts according to weight.}$$

This method of working requires 1·127 kil. of carbon per kilogramme of pig-iron, and as we have according to the composition of the charge, which serves for comparison, 27·2 kils. of iron, we find that only 0·91 of the iron produced is reduced in the zone of reduction by means of carbonic oxide, whilst 0·09 is reduced by direct contact with carbon in the zone of fusion and of gasification.

We have mentioned in Chapter XXV. a blast-furnace at Seraing, in the charges of which there are contained, per kilogramme of pig-iron produced, 0·363 carbonic acid = 0·099 carbon and 0·264 oxygen, next in the oxides 0·290 oxygen, and, finally, in the coke 1·333 carbon.

We get thus :

$$0\cdot099 \text{ C for } 0\cdot264 + 0\cdot099229 : 0\cdot38738 = 4\cdot1974 \text{ vols.}$$

The gases from the throat of the furnace contained :

Vols.			
11·39	C O ²	.. ..	= 5·695 C and 11·390 O
28·61	C O	.. ..	= 14·305 C „ 14·305 O
0·20	C ² H	.. ..	= 0·04 C ..
57·06	N	.. ..	= 20·04 C and 25·695 O
100·00	N	.. ..	= 35·121 C and 45·032 O
	loss	.. ..	= 26·519 C „ 26·519 O
	Excess	=	8·602 C and 18·513 O

and we get $0·38738 : 18·513 = 0·09229 : x = 4·4105$ carbon, which has been oxidized directly by contact with the oxide of iron. For 1 kil. of the pig-iron there has thus been used $8·602 : 4·1915 = 1·333 : x = 0·649$ kil. of carbon for the reduction by carbonic oxide, and 0·684 kil. for the reduction by means of solid carbon.

This direct reduction, carried to the extreme, is therefore greater than that produced by carbonic oxide, a state of affairs which is, however, perfectly justified, by the fact that one-half of the ores charged consists of finery slags, which, of course, cannot be reduced by the carbonic oxide.

It will thus be seen that the analysis of the waste gases becomes, even to the practical metallurgist, a valuable means of ascertaining what takes place inside the furnace, although the quality of the iron will at once show when the direct reduction exceeds the proper limits.

CHAPTER XXXII.

ON THE USE OF LIMESTONE AS A FLUX.

THE preceding investigations and considerations show that the addition of limestone to the minerals is to be considered rather as a means of regulating the temperature in the furnace, and of giving to the zone of reduction the necessary volume, than as

a means for causing the slags, into which this flux is transformed, to be more or less basic; for making the slags basic can also be translated "increasing the flux."

We have shown that the carbonate of lime begins to lose its carbonic acid at the temperature of 800° C.; and the analyses by Ebelmen show that this carbonic acid is not reduced to carbonic oxide, but that it only dilutes the reducing carbonic oxide, and diminishes, therefore, the action of the latter. Our experiments on reduction have already shown that an insignificant diminution in the quantity of the carbonic oxide, which is brought into contact with the ores in the unit of time, decreases the intensity of the reduction in a greater proportion; and this decides the question: whether it be better for the working of the blast-furnace to use the lime in the natural or in the calcined state.

In favour of the calcined lime is also its inferior specific heat at a high temperature. Although the specific heat (see Chapter X.) of the raw lime is at $100^{\circ} = 0.1666$, and that of the calcined lime $= 0.2169$, the elevation of the specific heat for temperatures increasing by 100° is, nevertheless, for raw lime $= 0.0710926$, and for calcined lime $= 0.0107899$; and 1 kil. of raw lime absorbs, when raised to the temperature of 800° , 340 calories, whilst the calcined lime absorbs only 199 calories. The use of calcined lime will therefore enlarge the volume of the zone of reduction to such a degree as corresponds with $304 - 199 = 105$ calories. The reason why different metallurgists have carried out various experiments on this matter with contradictory results is simply that the proportions of the quantities of lime and of carbon, due to one unit of weight of the crude pig-iron, are such that the quantity of the former is small, while that of the latter is abundant, and the advantage which the use of the calcined lime affords disappears under these conditions.

CHAPTER XXXIII.

COKE AND CHARCOAL.

HITHERTO, in commercial reports on the prices of pig-iron, there has been a difference made between the cost of coke and charcoal iron, the prices of the latter being always higher, on account of its superior quality. This superior quality of charcoal iron is in general attributed exclusively to the circumstance that coke contains such substances as silica, sulphur, phosphorus, &c., &c., which are more deleterious to the iron than charcoal. It cannot be denied that the existence of these substances in the coke may deteriorate the quality of the product, but they are surely not the only, and certainly not the chief, reason for the inferior quality of the latter, which depends more upon the management of the furnace adopted, partly from necessity and partly voluntarily, in the cases where coke is employed.

It is a generally-acknowledged fact, that a unit of weight of pig-iron requires a greater weight of coke than of charcoal to produce it. This fact is explained by the circumstance that 1 cubic mètre of coke weighs on the average 400 kils., whilst 1 cubic mètre of charcoal weighs only 230 kils. In order, therefore, to procure equal spaces of time during which the charges may pass through the zone of reduction, the charges have to be arranged in a corresponding manner, and the weight

of coke has to be taken $\frac{400}{230} = 1.74$ times greater than that of

charcoal; this coincides also with the practice mentioned above. Coke generally contains, however, more inorganic substances than charcoal, and the proportion between the amounts of carbon existing in the charges is not really 1:1.74, but is reduced to 1:1.5. The larger proportion of slag-forming materials contained in the coke—which materials have to be liquefied—bears, however, no important proportion to the larger contents of carbon; for 0.24 kil. of slag-forming material absorbs not more than $0.24 \times 60 = 14.4$ calories as latent heat, whilst 0.5 kil. of carbon produces at least $0.5 \times 2400 = 1200$ calories.

Such an increase in the quantity of heat produced, however, must necessarily effect a considerable augmentation of the volume of the zone of fusion, and consequently a corresponding diminution of the zone of reduction. On the other hand, the larger amount of carbon in the charges increases also the volume and the weight of the gases, without, however, increasing the proportion of carbonic oxide which they contain. This circumstance compensates, to a certain degree, the disadvantage of the diminished zone of reduction; for our experiments on reduction have shown that an augmentation in the quantity of gas passed in the unit of time accelerates the reduction. It is, however, not probable that this augmentation of the quantity of the gas fully compensates for the diminution of the volume of the zone of reduction, because the considerably larger quantity of heat acts more powerfully than the increased quantity of gas.

But there is yet another circumstance which still more diminishes the volume of the zone of reduction; this is the specific heat of the coke as compared with that of the charcoal. The specific heat of the former at 100° is 0.2415 , while that of the latter is 0.157139 (Chapter X.), but the increase in the specific heat for a rise of the temperature of 100° is for the former 0.0026 , and for the latter 0.019372 , whence the absorption of heat of 1.74 kil. of coke by its preliminary heating to $800^{\circ} = \{0.157139 + (3 \times 0.019372)\} \times 1.74 \times 800 = 299$ calories, whilst charcoal absorbs only $\{0.2415 + (3 \times 0.0026)\} \times 1. \times 800 = 199$ calories.

The volume of the zone of reduction is, therefore, diminished in this proportion, when coke is substituted for charcoal. Thus if this volume, for charcoal, $= 15$ cubic mètres, of which 10 cubic mètres are occupied by the charcoal, and 5 by the ores and flux, then if coke be used the volume will be reduced to $= \left(\frac{199}{299} \times 10 \right) + 5 = 11.62$ cubic mètres.

The necessary consequence of this considerable diminution of the volume of the zone of reduction is that the ores are no longer completely reduced before they arrive at the zone of fusion, and that a portion of the protoxide of iron is dissolved in the slag-

forming materials, from which it can only be reduced by contact with solid carbon at a very high temperature, when silicium and also phosphorus—the latter especially—are reduced and absorbed by the pig-iron in large quantities.

This direct reduction by means of solid carbon forms carbonic oxide, which absorbs for each kil. of carbon 2400 calories, and the volume of the zone of fusion is thus again diminished in favour of that of the zone of reduction; but the inferior quality of the coke pig-iron itself shows that the compensation thus afforded is but insignificant.

The ironworks in England prove, however, as stated by Gruner and Lan (*Etat présent de la métallurgie du fer en Angleterre*, p. 76), that the same fuel and the same ores may give very different products, and that the quality of the latter depends chiefly on the management of the blast-furnace. The pig-iron may, for instance, be caused to contain, even with charges of the same composition, a much less proportion of foreign substances, if the fuel is slowly consumed by a smaller quantity of air introduced per unit of time, for in this case the quantity of heat transmitted through the walls bears a larger proportion to the total amount of heat produced, whence the volume of the zone of fusion is diminished, and that of the zone of reduction increased. This is also the reason of the influence of the form and size of the blast-furnaces, as a variation in these details either accelerates or limits the cooling of the rising gases.

CHAPTER XXXIV.

THE PROPORTION OF ASHES IN THE COKE.

UNFORTUNATELY the proportion of ashes contained in the coke varies greatly even in the case of fuel obtained from the same mine, and whoever neglects to determine frequently the percentage of ashes of the coke received, is liable to various interruptions and irregularities in the working of the blast-furnace.

If, for example, 1 kil. of coke contains at one time 0·9 kil. of carbon, and at another time 0·7 kil., the quantity of heat produced will be in the one case 5040 calories, and in the other 3920 calories, and this change, of course, will alter all proportions of the blast-furnace. Moreover, the greater proportion of ashes in the coke does not increase the material for the slags in such a manner that this augmentation can be useful in any way, for these slags are only produced by the combustion of the coke in the hearth of the furnace.

My intention is to consider the chemical impurities of the pig-iron, and the influence of the other substances in the materials only in so far as their action is modified by the temperature in the furnace; but in speaking of the ashes in the coke, we must mention that they often contain large proportions of such substances as evidently act in a disadvantageous manner. I have found, for example, in the ashes of Belgian coke (ashes 26·91 per cent.) 0·2 per cent. of arsenic, 0·23 per cent. of sulphur, and 0·03 per cent. of phosphorus; whilst coke from the valley of the Saar with only 21·924 per cent. of ashes, contained 0·81 per cent. of arsenic, 1·29 per cent. of phosphorus, and 12·52 per cent. of sulphur.

The discovery of M. Saint Claire Deville makes it doubtful whether the proportions of alkalis in the residues of the fuel are of any great importance, but the opinion that alkalis are not, or only very seldom, contained in the ashes of the coke is decidedly wrong, for I have found in the ashes of the Belgian coke 1·89, and in that from the valley of the Saar 0·72 per cent. of alkalis Na O and K O, as well as in most of the ores which I have analyzed.

Silicium and phosphorus are the impurities the combination of which with the iron is most favoured by high temperatures and insufficient reduction; and even this circumstance proves that the silicium and the phosphorus originate rather from the coke than from the ores, because, if direct reduction by solid carbon takes place, they are reduced from the unconsumed coke, and they pass necessarily into the iron.

CHAPTER XXXV.

QUANTITY OF AIR INTRODUCED INTO THE BLAST-FURNACE.

THE quantity of air introduced into the blast-furnace can by no means be calculated—as is still stated in many treatises on metallurgy—from the pressure of the blast, and the section of the tuyere holes, for the blast does not enter a free space, but one which offers considerable resistance to its efflux.

The effective quantity of air introduced into the furnace can only be exactly obtained by an analysis of the gases of the throat of the furnace, and analyses of the charges. Let us consider, for example, the analysis of the gases of the blast-furnace at Clerval, as given by Ebelmen.

It gave:

Vols.	
12.88	$\text{CO}^2 = 12.88 \text{ O} + 6.44 \text{ C}$
23.51	$\text{CO} = 11.755 \text{ O} + 11.755 \text{ C}$
5.82	H
57.79	N
<hr/>	
100.00	

The charges during the month of September, 1841, consisted of:

90045	kils. of charcoal
11700	„ limestone
154800	„ Bohnerz (alluvial ore)
78800	„ calcareous ore

for $30 \times 24 = 720$ hours.

The hourly charges consisted, therefore, of:

125	kils. of charcoal
31.5	„ limestone
215.0	„ alluvial ore
109.4	„ calcareous ore.

The total production was 61170 kils. of pig-iron, or 85 kils. per hour.

The analysis of the mixture of the charges, inclusive of lime-stones, showed :

27.2	iron
12.0	oxygen
12.5	water
9.2	carbonic acid
20.0	silicic acid
6.6	clay
11.8	lime
0.7	oxide of manganese

100.00

The charcoal contained :

88.0	C
3.0	H
6.0	O
3.0	ashes

100.00

and produced by dry distillation :

3	per cent. of hydrogen
6	„ oxygen
4	„ carbon

An hourly charge contains, therefore :

									Material for the Slags.
125	kils. of charcoal	= 110.0	C 00	7.05	3.0	H 75	0.0	Fe 00	3.75
335.9	mineral substances								
	less:			23.81	out of Ca				
44.49	water	CO ² = 32.74 =	8.93	42.71	out of ores	96.80		139.15	
			118.93	C 74.02	O	3.75	H	96.80	Fe 142.90
311.41									

The analysis of the gases from the throat of the furnace shows 5.97 vols. per cent. of nitrogen, and as the nitrogen can neither appear nor originate from any source but from the blast introduced the volume of the oxygen introduced with it must have been = 79.04 : 57.97 :: 20.96 : x = 15.373 vols. But the analysis shows 24.635 vols. of oxy. and the difference,

= $24.635 - 15.373 = 9.262$ vols., must, therefore, come from the ores, the charcoal, the carbonic acid contained in the ores, and the limestone.

74.02 kils. of oxygen in the charges are equal to $\frac{74.02}{1.43028} = 51.7521$ cubic mètres, and the proportion between this quantity and the excess of oxygen in the gases is thus $51.7521 : 9.262$, whence the volume of the air introduced per hour can be calculated.

Namely:

$9.262 : 51.752 :: 57.79 : x = 322.90$ cubic mètres of N
 and $9.262 : 51.752 :: 15.373 : x = 85.898$ „ „ O
 408.798 cubic mètres of
 atmospheric air per hour = $\frac{408.798}{3600} = 0.11356$ cubic mètre
 per second.

The quantity of oxygen introduced per second is:

$\frac{85.898}{3600} = 0.02386 \text{ m}^3 = 0.02386 \times 1.43028 = 0.034127$ kil.

0.034127 kil. of oxygen combines,
 for the formation of carbonic
 oxide, with 0.025595 kil. of carbon,
 but the charges introduced into the
 furnace per second contain ac-

cording to the calculation .. $\frac{100}{3600} = 0.030556$ „ „

there remains thus: 0.004961 „ „

more than the oxygen of the air introduced could have consumed. It would, however, be very erroneous to consider this excess of carbon as a mistake in the analysis, for such an excess is due to the direct reduction of the oxide of iron by means of solid carbon, and signifies the quantity thus used.

Neither the pressure-gauge nor the number of strokes of the piston of the blowing-engine offers any but approximate means of determining the quantity of blast introduced, and it would be

useless to determine *a priori* this quantity and arrange the speed of blowing-engine accordingly; experience alone can show what is right in this respect.

The volume of air introduced determines, it is true, the number of hours required to reduce to a state of pig-iron the ores contained in the charges; but this time is, of all the factors relating to the action of the blast-furnace, that which can be determined with the least accuracy *a priori*, and which, moreover, is most frequently variable; for ores from the same mine differ very often with respect to the oxide of iron which they contain. It is, therefore, fortunate that, if the time allowed for passing through the zone of reduction is too short, the completion of the reduction of the oxides can still be accomplished by means of solid carbon, so as to prevent a portion of the iron from remaining dissolved in the slags in the state of protoxide.

CHAPTER XXXVI.

COST OF THE BLAST.

If a cylinder of a blowing-engine supplies per second one cubic mètre of air, and if the speed of the piston is one mètre, it of course follows that the sectional area of the cylinder must be equal to one square mètre; in order to obtain, therefore, successively the pressures corresponding to 0·01, 0·02, and 0·03 mètre of mercury, the pressure upon this sectional area must be 135·63, 271·26, and 406·89 kils., involving the use of as many kilogram-mètres of power. Dividing these values by 75, we get the number of horses' power* which are required for these pressures; and as

* The French horse-power is equivalent to 75 kilogrammètres (or 75 kils. raised to a height of one mètre) per second, this being equal to 32,549 foot pounds per minute, or about $\frac{1}{70}$ th part less than a British horse-power. In other words, 70-horse power, according to the French standard, equals about 69-horse power according to the standard adopted in this country.—TRANSLATORS.

3 kils. of coals are consumed per horse-power per hour,* the total consumption of coals may, therefore, be obtained by multiplying the number of horse-power by three. The result thus obtained is, however, increased by 25 per cent. on account of friction, loss of blast, clearance spaces in the cylinder, &c., &c. The following Table is calculated according to these statements:—

Pressure in centimètres of Mercury.	Consumption of Coals per hour for each cubic mètre of Air per second.	Pressure in centimètres of Mercury.	Consumption of Coals per hour for each cubic mètre of Air per second.
1	6·51	11	71·61
2	13·02	12	78·12
3	19·53	13	84·65
4	26·04	14	91·16
5	32·55	15	97·67
6	39·06	16	104·18
7	45·57	17	110·69
8	52·08	18	117·20
9	58·59	19	123·71
10	65·10	20	130·22

There are blast-furnaces which require as much as 6 cubic mètres of air per second, and the total consumption of fuel in any case can of course be obtained by simply multiplying the numbers given in the above Table by the number of cubic mètres of blast used per second.

CHAPTER XXXVII.

THE SAVING OF FUEL EFFECTED BY INCREASING THE PRESSURE OF THE BLAST.

SCHNEERER, in his 'Treatise on Metallurgy' (Brunswick, 1853, vol. ii., p. 188), says:—"Let us suppose that two blast-furnaces of the same construction are worked with charges exactly equal, a quantity of fuel relatively equal, and the same quantity of air,

* This is a somewhat excessive allowance.—TRANSLATORS.

but the one furnace, A, with a blast at a considerably less pressure than that supplied to the other furnace, B; the production of the furnace A will be absolutely less than that of the furnace B. The relatively increased quantity of fuel for the latter furnace can, therefore, be diminished, until the production of this furnace is equal to that of the furnace A."

We may well admit that Scheerer would not have written this sentence if the result of which he speaks had not been noticed either by himself or by some other competent observer; but it is, nevertheless, probable that these observers have deceived themselves, at least to a certain degree.

If we suppose, for example, one cubic mètre of air at 0° and 0.76 mètre pressure to be introduced per second, the quantity thus supplied will be sufficient for the combustion of 0.1575 kil. of carbon, or 567 kils. of carbon per hour, or about 600 kils. of charcoal. If this one cubic mètre of air retains in the furnace A a pressure of 0.03 mètre mercury, and in the furnace B a pressure of 0.09 mètre, the volume will be reduced to 0.96204 and 0.89411 cubic mètre respectively in the two cases.

If the temperature in both furnaces was, without the pressure of the blast, equal to 2800° , it would be increased by the pressure of the blast to 2910° and 3131° in the two cases respectively, and the volumes of the air at those temperatures would then be 11.222 and 11.154 cubic mètres, these volumes being almost identical; thus the resistance of the column of fusion would not be greater, if by the augmentation of the pressure in the proportion of 3:9 an increased velocity was not increased; but in the latter case the consumption of fuel in the unit of time would become larger, and thus also the amount of the charges that passes in the unit of time through the zone of reduction.

Of course, the fact of the combustion being more rapidly effected does not alter the proportion between the reducing gases and protoxide of iron contained in the ores; the latter, however, are exposed for a shorter time to the current of the gases, and they are thus less completely reduced, but the completion of the reduction, on account of the 221° higher temperature in the hearth, can be effected by solid carbon, without giving rise to

any irregular working. The same action takes place, therefore, in this case as when hot blast is used, namely, a larger quantity of the charges pass through the zone of reduction per unit of time, but the quality of the products is deteriorated.

But if now the quantity of the fuel is diminished, until the normal quantity of the charges passes through the zone of reduction per unit of time, it has to be observed, that the weight of one volume of charcoal is only $\frac{1}{10}$ of that of the ores, and that, therefore, for each kil. of fuel saved an additional 10 kils. of the ores comes into the shaft of the furnace. Let us suppose now that these ores contain 30 per cent. of iron = 43 per cent. of oxide of iron, we still get for 4.3 kils. more oxide of iron, 2.33 kils. less carbonic oxide, whence the direct reduction by means of solid carbon is again considerably increased. But if the same quantity of air as before is still introduced notwithstanding the diminished quantity of fuel in the charges, the direct reduction and the quantity of the charges that passes in the unit of time through the zone of reduction will be increased, for the less quantity of fuel is more quickly consumed by the admission of the constant quantity of air. This rapidity of passage of the charges as well as the direct reduction are, however, limited by the circumstance that each kil. of carbon used for direct reduction, absorbs 2400 calories, whence the temperature in the hearth is ultimately so much diminished, that the direct reduction ceases altogether.

The delusion, therefore, upon which the statement by Scheerer rests consists, very probably, of the circumstance that the quantities of air introduced into the furnaces A and B were not in reality equal, for the calculation of these quantities has been almost always made under the supposition that the air passed into a free space, the resistance of the column of fusion being entirely neglected.

We have shown that the quantity of the charges that passes in the unit of time through the zone of reduction can be increased by raising the pressure of the blast without augmenting its quantity; but the quantity of the blast must be diminished if the charges contain less carbon, and, of course, the quantity of the charges passing through the zone of reduction may then

again fall to the normal amount, but not without increasing the direct reduction and deteriorating the product.

An increase in the pressure of the blast, by 6 centimètres, produced an increase of temperature in the hearth of 221° . As 1 kil. of carbon produces, under this pressure, the temperature of 2910° , and the specific heat of the products being in this case proportionate to the carbon consumed, these 221° correspond with a saving of 0.076 kil. in the consumption of carbon, which is equal to 43.092 kils. of carbon, or 45.6 kils. of charcoal for an hourly charge. But the higher pressure of the air requires a larger engine-power, which corresponds again (if 3 kils. of coals are used per horse-power per hour) with 39.0 kils. of coals. It will thus be seen that this mode of saving fuel exists only in imagination.

CHAPTER XXXVIII.

CALCULATION OF THE RESISTANCE OF THE COLUMN OF FUSION.

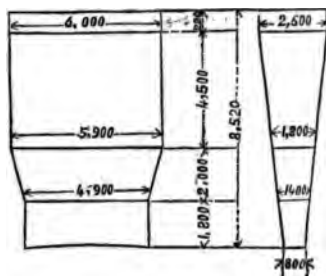
ALTHOUGH the irregularity in the form of the pieces of the materials forming the charges prevents us from making an exact calculation of the resistance of the column of fusion, the method of making this calculation, described and proved in Chapter XIV., is, nevertheless, of great value in comparing the resistances due to different constructions of furnaces or different methods of working.

For the purpose of instituting such a comparison we shall take the method of working the furnace followed at Seraing, when Ebelsen analyzed the gases at that place (Chapter XXV.), and we shall calculate results for the form of Raschette furnaces, shown by the annexed figures.

The furnace at Seraing had a capacity, exclusive of the zone of gasification, of 113.8 cubic mètres, while the capacity of that represented by the annexed figure is 82 cubic mètres, and the transmissi

$$\text{e, therefore, } \frac{113.8}{82} = 1.4$$

times larger than in the former. We have thus to introduce into the calculation for this transmission, instead of 1044 calories.



1461 calories, whence the temperature at the upper limit of the zone of gasification becomes :

$$\frac{4704 - 1461}{2 \cdot 19913} = \frac{3243}{2 \cdot 19913} = 1474^\circ.$$

The limits of temperature of the zone of fusion are thus 1474° and 800° , and the absorption of heat in this zone is:

For the preliminary heating, from

Degrees.	Kils.		Calories.	
800 to 1474 = 1	465 coke	$\times 674 \times 0.341183$	= 337	} = 675.
800 to 1100 = 1	iron	$\times 300 \times 0.149691$	= 45	
800 to 1300 = 2	205 slags	$\times 500 \times 0.2658085$	= 293	
By transmission		712×1.4	= 997	} = 1268.
By the latent heat of 1 kil. pig-iron		= 139	= 139	
" " 2	205 slags	$\times 60$	= 132	

The absorption in the zone of reduction is :

By preliminary heating, from

Degrees.	Kils.		Calories.	
500 to 800 = 1·465 coke		× 300 × 0·263693	= 116	} = 414.
500 to 800 = 2·381 ores		× 300 × 0·224300	= 166	
500 to 800 = 0·824 limestone		× 300 × 0·557654	= 138	
Heat of combination of				
	0·461 limestone	× 110	= 50	} = 622.
By transmission	.. .. 409	× 1·4	= 572	

The absorption of heat in the zone of preparation is :

For preliminary heating, from

Degrees.	Kils.		Calories.	
0 to 500 = 1.456	coke	$\times 500 \times 0.186197$	= 136	} = 469.
0 to 500 = 2.381	ores	$\times 500 \times 0.185920$	= 221	
0 to 500 = 0.824	limestone	$\times 500 \times 0.273284$	= 112	
By transmission	182	$\times 1.4$	= 255	} = 508.
By latent heat of 0.044	water	$\times 536.67$	= 23	
Heat carried off by the waste gases			= 230	

The volumes of the zones are, therefore :

			Cubic Mètres.	
Zone of fusion	1558 : 675 :: 82 : x	$x = 35.526$	} = 82.	
„ reduction	1558 : 414 :: 82 : x	$x = 21.790$		
„ preparation	1558 : 469 :: 82 : x	$x = 24.684$		

In order to calculate now the resistance in the column of fusion, we have at first to mark the limits of the zones in the vertical section of the furnaces, and then to determine the vertical height of each zone.

The limits of each zone have certain temperatures, and if we divide each zone into four or five parts at equal vertical distances, we may determine the average temperature due to each of these parts, as well as the section of this part itself.

The formulæ used for determining the resistance, and which have already been given in Chapter XIV., are : $\frac{KCF}{4S} \cdot p$ for

the friction, and np for the bends, where K represents the coefficient of friction = 0.024; CF the surface of contact; S the area of the free space between the pieces of fuel; and p the column of pressure corresponding with the velocity.

The area of the surface of contact depends upon the size of the pieces of fuel; if these pieces were of uniform size, and if this size could be exactly known, our calculation would approach the truth very nearly; and although this is not the case, we can, nevertheless, make such suppositions as will enable us to compare the resistances of different forms of furnaces. Let us suppose, therefore, that the pieces have a diameter of 5 centimètres; a cubic mètre of the shaft contains then $\left(\frac{1000}{50}\right)^3 = 8000$

pieces, and the surface of each piece is $= 0.05^2 \pi = 0.007854$ square mètres, consequently the surface of contact exposed by the pieces contained in one cubic mètre $= 62.832$ square mètres.

But the different portions of the shaft for which the resistance has to be calculated contain sometimes more and sometimes less than one cubic mètre, and the formula has to be transformed, therefore, in such a manner that the volume of the space must be multiplied by the constant $= 62.832$. Designating, therefore, the vertical height of the space by h , its section by s , and the free space between the pieces ($= s \times 0.2146$) by s_o , the formula becomes $h s = \frac{K C F}{4 s_o} \cdot p$.

In order to ascertain the value of p , we must first know approximately the volume of gas that passes per hour through the shaft. The furnace at Seraing produces per hour 708 kils. of forge pig-iron, or 0.1966 kil. per minute, and our furnace being smaller in the proportion of $\frac{82}{113.8}$, this production is reduced to 0.1417 kil.

Now as one kil. of iron requires 1.333 kil. of carbon $= 3.111$ kils. of carbonic oxide plus 5.852 kils. of nitrogen, and as these latter quantities together at 0° and a barometric pressure equal to 30 in. of mercury give a volume $= 7.143$ cubic mètres, we get for the calculation $0.1417 \times 7.143 = 1.01216$ cubic mètre; this volume we shall call V . But this volume is by no means constant, for at the beginning there are neither carbonic oxide nor nitrogen, but only atmospheric air; later on, moreover, it is increased by the absorption of hydrogen, water, &c., &c.

Of course, these modifications cannot be taken into account, but it is decidedly necessary to consider the temperatures which decrease as the gases ascend, and materially alter their volume.

The volume of the gases expanded by heat $= V$ multiplied by $1 + (0.003665 \times t)$; where t = temperature, and the product $= V_o$. The highest temperature at the level of the tuyeres is:

$$\frac{8000}{2.9337} \times \frac{1}{1 - \frac{0.680193}{7.2337}} = 3545^\circ \text{ (Chapter VII.)}$$

Having now determined the temperature, t , for each part of the shaft of the furnace, the volume, $= V_o$, and the section s_o , we find the velocity $\frac{V_o}{s_o} = v$ and the column of pressure $p = \frac{v^2}{2g}$.

The number of bends through which the gases have to pass is equal to n , and is obtained by dividing the vertical height of the part of the shaft by the diameter of the pieces.

The Tables on pages 169 and 170 have been calculated in this manner.

It has, however, to be observed that the zone of gasification, as already shown in Chapter XXIII., is in reality not filled with coke, but we may say the pieces of coke float in it; and this reduces the resistance considerably, for our investigations show, that the zone of gasification produces a very great resistance.

The pressure gauge of the furnace at Seraing showed 0.05 mètre of mercury, which corresponds with a column of gas of 571 mètres, thus being $\frac{571}{1159} = \frac{1}{20}$ of that obtained by calculation.

According to this there would be no resistance at a height of 1.75 mètre from the hearth, that is to say, about at the middle of the zone of gasification. If we deduct now from the calculated resistance for the furnace of Rachette's construction, the two first amounts, which correspond with about half the zone of gasification, the resistance in this furnace is reduced to a column of gas of 66 mètres, which is equal to about 0.007 mètre of the mercury gauge.

The necessary pressure of the air, if all circumstances are otherwise equal, is thus in Rachette's furnace $= 0.007$, and in the circular furnace $= 0.05$ of mercury, and the consumption of coal for producing the steam for the blowing-engine will be in the proportion of 5:33.

[illegible]

Height above the bottom of the Hearth.	Vertical height of the section of the Shaft.	Temperature.	Volume at 0°. V	Volume at F°. V _o	Area of the section. S	Area of the free Space. S _o	$\frac{V_o}{S_o} = v$	$\frac{v^2}{2g} = p$	n	Circular Furnace.		
										$h \frac{KCF}{410} \cdot p$	np	Total.
mètres.	mètre.	°	cu. m.	sq. m.	sq. m.	sq. m.	mètres.	mètres.	mètres.	mètres.	mètres.	mètres.
3315	0	3315	1·01216	14·162	0·79	0·1695	83·538	355·86	0	312·63	0	312·65
3085	0·5	3085	..	13·309	0·79	0·1695	78·504	314·27	10	272·80	3558·6	3830·90
2855	0·5	2855	..	12·456	0·79	0·1695	73·470	275·26	10	241·82	3142·7	3384·52
2625	0·5	2625	..	11·603	0·79	0·1695	68·442	238·86	10	239·02	2752·6	2991·62
2395	0·5695	2395	..	10·750	1·53	0·3983	32·470	54·662	11·39	54·686	622·6	677·286
2165	0·5695	2165	..	9·897	2·54	0·5451	18·156	16·810	11·39	16·818	191·47	208·288
1935	0·5695	1935	..	9·043	3·80	0·8155	11·090	6·271	11·39	6·275	71·43	77·705
1705	0·5695	1705	..	8·190	5·30	1·1374	7·201	2·644	11·39	2·6455	30·119	32·7645
1474	0·5695	1474	..	7·337	7·07	1·5172	4·836	1·192	11·39	1·1231	13·582	14·7051
1362	0·5361	1362	..	6·480	9·08	1·9485	3·326	0·564	10·72	0·5315	6·0469	6·5784
1250	0·5361	1250	..	6·064	11·34	2·4336	2·492	0·316	10·72	0·2982	3·3956	3·6938
1138	0·5362	1138	..	5·649	12·57	2·6975	2·094	0·223	10·72	0·2106	2·3979	2·6085
1026	0·5362	1026	..	5·234	11·34	2·4336	2·151	0·236	10·72	0·2221	2·5288	2·7509
914	0·5362	914	..	4·818	10·46	2·2447	2·146	0·235	10·72	0·2259	2·5191	2·7450
800	0·5362	800	..	4·403	9·62	2·0644	2·133	0·232	10·72	0·2328	2·4867	2·7195
725	0·5714	725	..	3·980	8·81	1·8906	2·105	0·226	11·43	0·2268	2·5827	2·8095
650	0·5714	650	..	3·702	8·04	1·7254	2·145	0·235	11·43	0·2356	2·6856	2·9212
575	0·5715	575	..	3·503	7·30	1·5666	2·236	0·255	11·43	0·2560	2·9142	3·1702
500	0·5715	500	..	3·145	6·60	1·4163	2·220	0·251	11·43	0·4439	2·8684	3·3123
420	1·0049	420	..	2·867	5·31	1·1395	2·516	0·323	20·10	0·5698	6·4916	7·0614
340	1·0049	340	..	2·570	4·71	1·0108	2·543	0·329	20·10	0·5820	6·6121	7·1941
260	1·0049	260	..	2·273	4·15	0·8906	2·553	0·332	20·10	0·5866	6·6796	7·2592
180	1·0049	180	..	1·977	3·63	0·7790	2·537	0·328	20·10	0·5796	6·5921	7·1717
100	1·0050	100	..	1·680	3·14	0·6738	2·493	0·317	20·10	0·5595	6·3711	6·9306
5·0246	1·0050	100	..	1·680	3·14	0·6738	2·493	0·317	20·10	0·5595	6·3711	11589·3649

CHAPTER XXXIX.

CONCLUSIONS DERIVED FROM THE PRECEDING CHAPTERS.

I TRUST that I have clearly explained to the reader in the preceding chapters how the working of a blast-furnace may be modified in various ways; and I hope next to demonstrate, by giving it a numerical value, how each separate factor influences the working of the furnace.

We have seen that some of these factors act exclusively, so as to augment the production and increase the quantity by deteriorating the product, whilst others ameliorate the quality of the product, but require limited production.

A perfect process, however, does not consist in producing at will at one time a good quality and a small quantity, and then again a large quantity of an inferior quality; but in a mode of working considering equally quantity and quality, as well as the economy of production. Until the present time the effective progress of the iron manufacture has been retarded by the total want of a clear understanding of the action that takes place in the blast-furnace, and by the prejudice always connected with the handicraft, preventing the attainment of a better knowledge.

Especially the supposition that the melting of the iron and the slags requires a much higher temperature than is really the case, has produced the absurd axiom: "The higher the temperature, the better is the working of the furnace."

Of course a maximum temperature is necessary, when the ores have not already been reduced in the zone of reduction, because the direct reduction which then takes place absorbs much heat, and if sufficient heat did not exist the half-molten material would set; but this high temperature is surely not necessary, if all the ores, or at least the greater portion of them, are completely reduced before entering the zone of fusion. For effecting complete reduction a sufficient quantity of carbonic oxide is, however, the chief requisite, and this only originates from the carbon contained in the charges; but if this quantity of carbon is much

increased, the temperature is increased also, for the temperature increases in the same proportion as carbon is added for combustion; the transmission through the walls of the furnace of course being allowed for. An efficient reduction of the ores is impossible without a sufficient quantity of carbon, while on the other hand the increased quantity of the carbon is again opposed to the reduction, for the high temperature augments the volume of the zone of fusion, and diminishes, therefore, that of the zone of reduction, and the diminution of the zone of reduction diminishes also the time during which the ores and carbonic oxide remain in contact, and consequently the reduction itself.

In order to avoid this inconvenience, ores containing less iron are added to the charges, and if such ores cannot be obtained, limestone and other mineral substances are substituted. This quantity of slag-forming material diminishes the volume of the zone of fusion, by absorbing heat, and as these additional substances increase at the same time the volume of the charges, the iron contained in the latter passes more slowly through the shaft of the furnace, and the time during which the ores and carbonic oxide remain in contact is thus prolonged.

The heat, absorbed by the material for the slags apparently in a useless manner, is no loss, for the reduction does not require a large quantity of heat, but a temperature between 500° and 800° , and, especially, a quantity of carbonic oxide as large as possible. The disadvantage of the large proportion of slags is the space occupied by it in the zone of reduction; as the space could be better utilized if filled with oxide of iron. The disadvantage is still greater if the ores themselves contain a large quantity of slag-forming matters, because it is then more difficult for the carbonic oxide to penetrate these ores.

If we could eliminate, therefore, the excess of heat produced by the carbon, in any other manner than by using large quantities of material for forming slags, we should diminish the volume of the zone of fusion, and increase that of the zone of reduction; while we should besides add to the contents of the latter more oxide of iron, and should augment the production without deteriorating the quality of the product. We could, also, then add

to the charges any quantity of carbon which might be sufficient for the complete reduction of a charge rich in ores, before it enters the zone of fusion.

The existence of the zone of preparation is another circumstance that limits the volume of the zone of reduction. Although the preliminary heating of the charges cannot be avoided, as the reduction requires a certain temperature, the zone of preparation, occupying, as it does at present, a space in the shaft of the furnace itself, has, nevertheless, three important disadvantages. It adds to the gases of the mouth of the furnace the water contained in the charges, and thus makes these gases less fit for any further use; it absorbs a part of the heat of these gases, thus limiting still more their useful application, whilst the preparation or preliminary heating of the charges could be effected in a more economical manner by consuming a part of the gases, free from water, and still possessing a temperature of 500° ; and finally the existence of the zone of preparation renders an increased pressure of the blast necessary, and this increase becomes greater the smaller the section of the zone.

A prompt and complete reduction of the ores is chiefly opposed by the circumstance that the gases produced in the zone of gasification contain, besides carbonic oxide, 65·344 per cent. of nitrogen, besides the free hydrogen and the carbonic acid originating from the limestone and produced by the reduction itself.

Although free hydrogen is, as is known, a more efficient reducing agent than carbonic oxide, if both are in a pure state, the former absorbing the oxygen more promptly and completely than the latter, yet it is, nevertheless, of no effect in the shaft of the blast-furnace. The reason, however, for this inefficiency of the hydrogen can only be the diluted state in which it exists in the shaft of the furnace. If we allow a sufficient quantity of pure carbonic oxide to pass over oxide of iron, a quicker and more complete reduction will be obtained than by applying carbonic oxide produced by the combustion of carbon in atmospheric air, and thus diluted by nitrogen; and this proves that this dilution, although a necessary inconvenience, is not on that account a less disadvantage in the working of the blast-furnace.

After I had acquainted myself, by deep study, with all the conditions of the actual working, my great aim was to avoid the above-mentioned inconveniences, at least to a certain extent, and my efforts have not been without success.

My results have been patented in the principal countries of Europe, under the title, "Process for partly Eliminating the Nitrogen in the Products of Combustion;" and under the protection of this patent, I shall describe minutely in the following chapters the application of this process to the blast-furnace. The reader will thus be convinced that this mode of working will allow of an increase in the production of the furnace without deteriorating the quality of the product.

CHAPTER XL.

PROCESS FOR PARTLY ELIMINATING THE NITROGEN IN THE PRODUCTS OF COMBUSTION.

If a volume of carbonic acid is allowed to pass over carbon or any substance containing carbon, raised to a red heat, half a volume of carbon will be absorbed, and two volumes of carbonic oxide will be produced. Now by burning this carbonic oxide with atmospheric air, there are formed two volumes of carbonic acid mixed with 3.771 volumes of nitrogen. If the hot products of combustion are again brought into contact with incandescent carbon, there are formed four volumes of carbonic oxide, mixed with 3.771 volumes of nitrogen, this proportion of nitrogen being only half as great as the gases of the blast-furnace would otherwise contain, and the percentage of carbonic oxide being thus increased from 34.65 per cent. to 51.47 per cent.

Two volumes of carbonic oxide, = 2.503 kils., produce by their combustion $2.503 \times 2400 = 6007$ calories, and the products of combustion are:

$$\begin{array}{lcl} 3.933 \text{ kils. of } \text{CO}^2 & \dots & \left. \begin{array}{l} \text{the specific} \\ \text{heat of which} \end{array} \right\} \begin{array}{l} \{ 0.85108 \} \\ \{ 1.1562 \} \end{array} \end{array} \left. \begin{array}{l} \\ \dots \end{array} \right\} \begin{array}{l} \\ \end{array} \left. \begin{array}{l} \\ \end{array} \right\} 2.00728;$$

and the resulting temperature is therefore $\frac{6007}{2.0073} = 2292^{\circ} \text{ C.}$

The 3.993 kils. of CO^2 contain 1.0727 kil. of C; and the CO^2 , when being again reduced to CO, takes up the same quantity of carbon, and thus again absorbs 2400 calories per kil., and therefore 2574 calories. The final temperature of the zone of gasification, without considering the transmission and the preliminary heating of the carbon, would therefore be.

Specific heat of 5.006 kils. of CO = 1.2410 } 2.3972
 " " 4.738 " N = 1.1562 }

$$\frac{6007 - 2574}{2:3972} = 1432^{\circ} \text{ C.}; \text{ this temperature becomes, by the pre-}$$

liminary heating of the fuel,

$$1432 \times \frac{1}{1 - \frac{0.40898}{2.397}} = 1726^\circ.$$

It will be seen that the height of this temperature, even after allowing for some losses by the transmission through the walls of the furnace, is still sufficient for melting ordinary charges.

But if rich ores can be melted by this process with a minimum of material for slags, the latent heat absorbed in the zone of fusion will be increased. If, for example, the proportion between the amounts of slags and pig-iron is 1 : 2 instead of 2 : 1, the latent heat which is absorbed becomes $60 + (139 \times 2)$ instead of $(2 \times 60) + 139$, for the latent heat of the slags is = 60, that of forge iron = 139; while in producing foundry iron the amount would be $60 + (2 \times 175)$ instead of $(60 \times 2) + 175$.

Considering this increased absorption of heat, an increase of the temperature appears to be desirable, while there will be no fear that a direct reduction of the iron in the slags will take place.

This higher temperature is easily obtained, if the carbonic oxide as well as the air necessary for its combustion are subjected to a preliminary heating.

2 volumes CO = 2·503 kils., absorb, when heated to

Degrees.	Calories.	Degrees.	Calories.
100	62	400	248
200	126	500	310
300	187		

4·916 volumes of air = 6·177 kils., absorb, when heated to

Degrees.	Calories.	Degrees.	Calories.
100	150	400	603
200	301	500	753
300	452		

The temperature at the limit of the zone of gasification, if the gas and air are heated to 500°, becomes, therefore,

$$\frac{(6007 + 310 + 753) - 2574}{2 \cdot 3972} \times \frac{1}{1 - \frac{0 \cdot 49616}{2 \cdot 3972}} = 2365^{\circ} \text{C.}$$

The great question is now :—Can pure carbonic oxide be produced for this purpose cheaply and in sufficient quantities?

We shall, in a separate chapter, state the methods by which carbonic oxide can easily be produced in large quantities; but whichever method may be adopted, all require large quantities of heat. We shall show that these quantities of heat can be obtained without expense, if the gases from the blast-furnace, without being too much cooled, and containing as little aqueous vapour as possible, are applied to that purpose; for the richness of the gases obtained in this manner is not only of advantage for the reduction of the ores, but also for other applications. The statement of the principles of this process shows that $\frac{1}{4}$ of the carbon used for charging the blast-furnace serves to produce the carbonic acid, $\frac{1}{4}$ serves for the reduction of this carbonic acid to carbonic oxide, and $\frac{1}{2}$ enters the shaft and the zone of gasification as coke or charcoal in the charges.

Now, whether the carbonic acid is obtained from limestone or from the products of distillation of pit coal, the cost for this part of the carbon consumed will always be *nil*, for the calcined lime or the coke obtained can always be utilized.

The second quarter of the carbon required can be obtained from all sorts of waste materials, which so abound in iron works, and the value of which is scarcely half of that of the coke that would otherwise be required for the charges of the furnace. Calculating the ton of coke at 15 francs per ton, 3.75 francs or 25 per cent. will thus be saved. Of course, wages have to be paid, but two men will be sufficient for producing the quantity of gas corresponding to an hourly consumption of 1 ton of carbon, and this labour will not cost more than 0.50 franc; while charging 25 centimes per hour for the capital invested in the apparatus, we still get a net saving of 20 per cent.

Without taking into consideration the form of the blast-furnace especially adapted for the application of this process, the smaller power required for the blowing-engine will also increase the saving effected, for the proportion between the volume to be introduced, and that required by the ordinary method is 6.9 : 9.8. The richness of the reducing gases allows the use of charges containing a higher percentage of iron, and gives the power of producing per unit of time almost twice as great a quantity as under ordinary circumstances; and this latter advantage will consequently be the chief reason for increasing the value of this process in the eyes not only of practical metallurgists, but also of those who undervalue the quality of the product.

CHAPTER XLI.

THE PRODUCTION OF CARBONIC OXIDE.

I HAVE already stated, in Chapters III. and IV., "Surface of Contact," and "Influence of the Temperature on the Process of Combustion," the conditions for the formation of carbonic oxide. When I undertook to ascertain, by my experiments on reduction, the influence of larger quantities of carbonic oxide in proportion to the existing nitrogen, I had to produce large quantities of carbonic oxide, and I used this opportunity for ascertaining the best and cheapest method of producing this gas.

The preparation of carbonic oxide by treating red prussiate of

potash with sulphuric acid was decidedly the most convenient and, therefore, the cheapest for the quantities required by me; 100 grammes of the salt giving 35 litres of gas. But when the experiments, which led to this preparation of carbonic oxide, showed that an increase in the proportion of carbonic oxide in the blast-furnace had such a favourable effect, and contributed even towards the heavy expenses of the production of this gas in a pure state, the problem of how this production could be best effected became still more important to study.

Former experiments had shown that the reduction of the carbonic acid to carbonic oxide was the more completely and quickly effected the higher the temperature of the carbon with which the carbonic acid came in contact. But a high temperature costs more than a lower one in the proportion of the squares of the respective temperatures, whilst the quickness and the completeness of the reduction increase in a similar proportion, so that one progression almost compensates for the other one. A moderate temperature for the operation is, therefore, decidedly to be preferred, as the apparatus then lasts a longer time, and its management becomes much more easy. The experiments made showed that carbonate of lime is completely decomposed in two hours if the temperature = 1000°C ., and the width of the retorts in which the decomposition is effected does not exceed 25 centimètres. At the same temperature the reduction requires, per cubic mètre of carbonic acid and per second, 1770 square mètres of surface of contact. One cubic mètre of limestone in pieces weighs 1300 kils., and contains 572 kils. of carbonic acid = 291 cubic mètres. The time required for the decomposition being two hours or 7200 seconds, the retort produces per second 0.04 cubic mètre of carbonic acid, and the necessary surface of contact is = $1770 \times 0.04 = 70.8$ square mètres; one cubic mètre of fuel in pieces of 0.04 mètre diameter has a surface of contact of 78 square mètres, and retorts of equal size would thus suffice for the decomposition and reduction. But as the carbonic acid produced per retort of 1 cubic mètre capacity absorbs 156 kils. of carbon, and as 1 cubic mètre of coke weighs 400 kils., it will be more advantageous to make the capacity of the retorts

for reduction twice as great, in order to avoid the necessity of filling them more frequently than every four or five hours. A retort capacity of 3 cubic mètres will thus produce per hour 364 kils. of carbonic oxide = 156 kils. of carbon, half of which originates from the limestone, and the other half from the fuel in the retorts of reduction. If the 728 kils. of calcined lime obtained can be utilized, this operation is more economical than if the lime was calcined in kilns, because 1300 kils. of limestone require the consumption in a kiln of between 312 and 390 kils. of pit coal, whilst a Silesian zinc distilling furnace, with retorts of a capacity of 3·64 cubic mètres, consumes per hour, if heated with gas, but 67·5 kils. of pit coal, which corresponds with 111 kils. for two hours and a capacity of the retorts of 3 cubic mètres. But these 111 kils. of coals produce from the limestone 156 kils. of carbon, and the profit from $(156 - 111) \times 12 = 540$ kils. in 12 hours more than compensates for the additional expense of the apparatus and the wages for its working.

The other half of the carbon contained in the carbonic oxide may be obtained either from small waste pieces of coke, or from larger and more useful ones; but the former being of less value than the latter, and even sometimes without any value, this half of the carbon can also be obtained more cheaply than from the coke of good quality which would have to be supplied with the charges introduced at the mouth of the blast-furnace.

If the carbonic oxide consumed in the blast-furnace has, however, to be produced in very large quantities, the production of calcined lime might soon become too great, and it would then be more advantageous to partially substitute for the limestone another substance.

The simplest and most convenient mode is then to effect the reduction of oxide of copper or oxide of iron by means of the products of distillation from pit coals or other suitable substances; water and carbonic acid are thus formed, and the former is separated by cooling from the latter, which is reduced to carbonic oxide by passing it over red-hot carbon. Small coal is in most cases best adapted for this purpose, because the coke produced may be directly used for the blast-furnace.

100 kils. of coals give, for example (according to their nature),
67 kils. of coke, and the fluid products contain

23·68 kils. C, which reduces $314\cdot551$ Cu O and forms $86\cdot80$ C O^g
and 4·85 kils. H „ $192\cdot445$ Cu O „ 43·65 water

507·096 Cu O.

In order to compare this method of preparing carbonic oxide with the preceding one, we have to calculate what quantity of coal is required for 572 kils. of carbonic acid. If 100 kils. of coals produce 86·8 kils., it becomes 659 kils. of coals :

which give 441·5 kils. of coke, and 156·05 kils.

C, in the fluid products, which reduce .. ^{Kils.} 2072·86 Cu O,
and produce 572 kils. C O^g, and 31·96 kils. of

hydrogen, which reduce 1268·81 Cu O,
and produce 287·6 kils. of water.

3341·67 Cu O.

By condensing the water and bringing the carbonic acid into retorts filled with small coal in a red-hot state, 156 kils. of carbon are once more absorbed, this requiring 70·8 square mètres of surface of contact, which correspond with a volume of 1 cubic mètre of small coal; we should, however, take, for convenience and safety, 2 cubic mètres.

The distillation of the coals requires six hours, and another hour is necessary for removing the coke and for the re-oxidation of the oxide of copper; the retorts must, therefore, contain 2306 kils. of coals and 11,696 kils. of oxide of copper. One cubic mètre of coals weighing 850 kils., the capacity of the retort will be = 2·71 cubic mètres. One cubic mètre of oxide of copper weighs 2000 kils.; but we have to take for greater safety one-third more of the oxide of copper, and the capacity of the retort for this oxide is thus = 7·79 cubic mètres.

For two hours there are thus necessary

2·71 cubic mètres for coals

7·79 „ „ oxide of copper

2·00 „ „ small coal

12·50 cubic mètres of retorts at a temperature of 1000°.

This gives per hour a consumption of 229 kils. of pit coals for the production of 156 kils. of carbon in the form of carbonic oxide.

In this case the accessory products are 441.5 kils. of coke, which have produced 188 kils. of combustible gases, of which 156 kils. have been absorbed by the final product, namely, the carbonic oxide; the quantity of coals consumed is thus reduced to $229 - 78 = 151$ kils.

As moreover the small coal used for the reduction of the carbonic acid, and which for the production of 156 kils. of carbonic oxide amounts to 78 kils., has a price not more than half that of good pit coals, the consumption of coals for heating the retorts will be compensated for, notwithstanding that the 229 kils. of coals represent but 156 kils. of carbonic oxide.

The retorts filled with oxide of copper never need be opened more than is necessary for admitting a sufficient quantity of air for the re-oxidation; in order to effect this operation rapidly, the retorts should be connected with an exhausting apparatus, which will cause 416.3 kils. of oxygen to be passed through per hour, thus for each two retorts which communicate with one retort containing coals, there will be caused to pass 1787 kils. of air, or 0.385 cubic mètre per second.

The 441.5 kils. of coke obtained may be removed during the time necessary for the oxidation of the oxide of copper, and the retorts are to be filled at the moment when the oxide of copper has become oxidized. When the carbonic oxide is prepared from limestone, the gas can be immediately accumulated in a gas holder, a slight negative rather than a positive pressure being maintained in the latter; if on the contrary the last described method of preparing carbonic oxide is employed, it is the CO^2 that accumulates in the gas holder, and passes thence into the retort of reduction. As the carbonic oxide ought to be applied to the blast-furnace with a certain temperature, it can thus pass from the retort of reduction directly into the furnace, and the method of production last described is in this respect preferable to that in which lime is used.

The following is a third method of preparing carbonic oxide

valent for 362 kils. of pit coals, except in localities where the iron ores are very dear.

Such a mode of utilizing of the puddling slags would, however, under ordinary circumstances, be more advantageous, as far as the quality of the product is concerned, than the usual method, which consists in adding these slags to the charges.

CHAPTER XLII.

UTILIZATION OF THE GASES OF THE BLAST-FURNACE.

The gases from the mouth of a coke furnace at Vienna, analyzed by Ebelmen, contained :

Vols.		Kils.
10·938	CO ^a	= 21·511
23·841	CO	= 29·837
2·342	H	= 0·210
57·335	N	= 72·045
5·544	aqueous vapour	= 4·462
<hr/>		<hr/>
100·000		128·065

The proportion of water is thus, according to weight, 3·5 per cent., and the gases will remain saturated with vapour, even when they are cooled to 35° or 36° C., so that the gases cannot be ameliorated by cooling.

The 29·837 kils. of carbonic oxide require for their combustion 17·049 kils. of oxygen, and the 0·21 kil. of hydrogen requires 1·68 kil. ; 61·653 kils. of nitrogen pass with these 18·729 kils. of oxygen into the products of combustion, which have thus the following composition :

Kils.		
68·407	CO ^a	} the specific heat of which is { $\begin{matrix} 14\cdot803 \\ 32\cdot622 \\ 3\cdot017 \end{matrix}$ } 50·442.
133·696	N	
6·352	aqueous vapour	

	Calories.
The 29·837 kils. CO produce ..	$29·837 \times 2400 = 71609$
and the 0·21 kil. H produces ..	$0·21 \times 34000 = 7140$
	<hr/> 78749
minus the latent heat of 1·68 kil. of water formed	= 1062
	<hr/> 77687

the resulting temperature is, therefore: $\frac{77687}{50·442} = 1540^{\circ} \text{C.}$

Now by eliminating the nitrogen in the manner previously described, and also all the aqueous vapour, but without altering the other proportions, the gases would have the following composition, without considering the hydrogen which originates chiefly from the air introduced, and of which the quantity is thus smaller, because only half as much air is introduced:

Vols.	Kils.	
51·641 CO	64·628	} requiring for their combustion 29·652 O, which is mixed with 97·610 N
48·859 N	60·765	

whence the following products of combustion are obtained:

Kils.	
94·280 CO ²	} the specific heat of which = $\left\{ \begin{array}{l} 23·372 \\ 38·643 \end{array} \right\} 62·015,$
158·375 N	

the production of heat is 64·628 kils. CO \times 2400 = 155107 calories, and the resulting temperature = $\frac{155107}{62·015} = 2501^{\circ} \text{C.}$

But if the gases escape with a temperature of 500° , they still contain:

$$\begin{array}{l} 64·628 \times 0·2479 \times 500 = 7828 \\ 60·765 \times 0·2440 \times 500 = 7413 \end{array} \left. \vphantom{\begin{array}{l} 64·628 \\ 60·765 \end{array}} \right\} 15241 \text{ cal.}$$

whence the temperature will be $\frac{155107 + 15241}{62·015} = 2747^{\circ} \text{C.}$

Of course the carbonic acid formed by reduction and mixed with the gases is, in this case, not taken into consideration; if we value it at $\frac{1}{3}$ of the carbon, we still have 113565 calories per 100 cubic mètres of gas. 100 cubic mètres of these gases contain 27·697 kils. of carbon, and 1 kil. of carbon that enters the furnace would produce in the gases, according to this suppo-

$$\text{position, } \frac{113565}{27·697} = 4100 \text{ calories}$$

CHAPTER XLIII.

APPLICATION OF THE PARTIAL ELIMINATION OF THE NITROGEN.

THE furnace at Mägdesprung, when producing foundry iron, furnished, according to Chapter XXIX., 94 kils. of pig-iron per hour; the volume of the zone of reduction was 10·753 cubic mètres, the time occupied by the ores in passing through that zone was 14 hours 9 minutes, and 1·373 kil. of carbon was consumed per kil. of pig-iron.

The ores contained 27 per cent. of iron, and the fuel was charcoal; the capacity of the shaft of the furnace was 26·55 cubic mètres.

Choosing now for the application of the partial elimination of the nitrogen a furnace on Rachette's system, with a capacity of 81·3 cubic mètres, and substituting for the charcoal, coke containing 80 per cent. of carbon, we may suppose that, on account of the diminished transmission, 1·333 kil. of carbon is sufficient per kil. of pig-iron.

In order to obtain charges containing more iron without, however, using ores which are reduced with more difficulty than those of Mägdesprung, we shall take brown iron ores containing 36 per cent. of iron.

We get thus for 1 kil. of iron, 1·400 kil. of slags, 0·159 carbonic acid, and 0·218 water = 2·777 kils. ores; next, 1·333 kil. of carbon + 0·26 kil. of slag-forming material = 1·359 kil. of coke; and finally, 0·010 kil. of calcined lime for combining with the silicic acid.

The quantity of slags after the fusion will be then = 1·4 + 0·01 + 0·26 = 1·670 kil. per kil. of pig-iron, and 1·333 kil. of carbon.

Half of the carbon is introduced into the furnace as carbonic oxide, and we get thus :

$$\frac{1 \cdot 333}{2} = 0 \cdot 666 \text{ C} = 1 \cdot 554 \text{ CO, which, at 2400 cal.} \\ \text{per kil., produce Cals.} \quad 3729$$

The other half, which reduces the CO² formed again to CO, absorbs, however 0.666 × 2400 = 1598

whence the produced heat is 2131

The combustion of 1.554 CO requires

0.888 O, which is mixed with 2.923 N.

We get thus :

$$0.888 + 1.554 + 0.666 =$$

$$\left. \begin{array}{l} \text{Kils.} \\ 3.108 \text{ CO} \\ 2.923 \text{ N} \end{array} \right\} \text{the specific heat of which} = \left\{ \begin{array}{l} 0.77004 \\ 0.71322 \end{array} \right\} 1.48326,$$

the resulting initial temperature, therefore,

$$= 2131 \times \frac{1}{1 - \frac{0.40898}{1.4832}} = 1984^{\circ}.$$

The absorption of heat in the shaft is now :

For heating

Kils.	Deg.	Deg.	Deg.	Calories.
1 pig-iron	to 1984 or 1200	(average 1597)	× 0.15047	= 118
0.666 carbon	to 1984 or 1300	(" 1642)	× 0.45741	= 208
1.670 slags	to 1984 or 1300	(" 1642)	× 0.34085	= 389
2.777 ores	to 1200 or 500	(" 850)	× 0.21563	= 491
0.010 lime	to 1300 or 500	(" 900)	× 0.30322	= 2
0.679 coke	to 1300 or 500	(" 900)	× 0.31212	= 169
Heat of combination of 0.159 kil. CO ²		× 251	.. ..	= 40
Latent heat	1	" pig-iron	× 175	.. .. = 175
"	1.670	" slags	× 60	.. .. = 100
Evacuation of the gases at 500°				= 1.48326 × 500 = 781

= 2473.

Deducting this absorption from the production, we have :

$$\begin{array}{r} \text{Calories.} \\ 1.48326 \times 1984 = 2942 \\ - 2473 \\ \hline \end{array}$$

and we only get for the transmission 469 which is evidently too little.

This small number is obtained by neglecting the heat, which

1·554 kil. of carbonic oxide would have produced by their direct combustion, namely, $0·666 \times 2400 = 1598$ calories.

We have, therefore, to restore a portion of this heat by a preliminary heating of the blast, and the carbonic oxide introduced. These gases heated to 100° give, according to Chapter XL. :

$$\begin{array}{l} \text{Calories.} \\ = 2·503 : 62 = 1·554 : x = 38·5 \\ = 6·177 : 150 = 3·811 : x = 92·5 \end{array} \} = 131.$$

Heating these to 500° , we get :

$$(2131 + 655) \times \frac{1}{1 - \frac{0·50584}{1·48326}} = 4228 \text{ cal.}$$

whence remain for the transmission $4228 - 2473 = 1755$ cal.

If we take of this 45 per cent. for the zone of gasification, the final temperature of this zone will be equal to $\frac{4228 - 790}{1·48326} = 2318^\circ \text{ C.}$

We have now to ascertain whether this temperature is sufficient for smelting all the materials, or whether it is after the completion of this operation still higher than the point of fusion.

The quantity of heat necessary for fusion is :

For heating

Kil.	Deg.	Deg.	Deg.	Calories.
1 pig-iron	to 2318	or 1200 (average 1754)	$\times 0·15647$	$= 175$
0·666 carbon	to 2318	or 1300 (" 1809)	$\times 0·48647$	$= 330$
1·670 slags	to 2318	or 1300 (" 1809)	$\times 0·35961$	$= 611$
Latent heat of iron and slags	..	..	..	$= 275$

$$\text{The temperature is, therefore} = \frac{4228 + 1391 - 790}{1·48326} = 1380^\circ.$$

This temperature is too high by 80° , for the point of fusion of the slags is not higher than 1300° . Such an excess of temperature would only increase the volume of the zone of fusion at the expense of that of the zone of reduction, as is at present the case with the ordinary working of the blast-furnace.

By heating, to 100° , the gases introduced by the blowing-engine, the quantity of heat produced becomes

$$(2131 + 131) \frac{1}{1 - \frac{0.43320}{1.48326}} = 3195 \text{ calories,}$$

and there remain for transmission $3195 - 2473 = 722$ calories. This is very little, if compared with the practical results formerly obtained, but this number is, nevertheless, justified by the low temperature which exists, and which of course diminishes the transmission.

If we again apportion 45 per cent. of the transmission = 325 calories, to the zone of gasification, the final temperature of that

$$\text{zone will be} = \frac{3195 - 325}{1.48326} = 1935^{\circ} \text{ C.}$$

The heat necessary for the fusion will then be :

For heating

Kil.	Deg.	Deg.	Deg.	Calories.
1 pig-iron	to 1935 or 1200	(average 1562)	$\times 0.14848$	109
0.666 carbon	to 1935 or 1300	(" 1617)	$\times 0.44773$	189
1.670 slags	to 1935 or 1300	(" 1617)	$\times 0.33460$	355
Latent heat of iron and slags..	..	..	..	275
				$\left. \begin{array}{l} \\ \\ \\ \end{array} \right\} = 928.$

The final temperature, after the fusion, will then be :

$$\frac{3195 - 325 + 928}{1.48326} = 1309^{\circ}.$$

Transferring the zone of preparation, for reasons stated in Chapter XXXIX., to above the shaft of the blast-furnace, the capacity of the shaft, = 81.3 cubic metres, will be only occupied by the zone of fusion and that of reduction ; and the respective volumes of these zones will be determined according to the absorption by preliminary heating in them, this absorption being for the zone of fusion :

Kils.	Deg.	Deg.	Deg.	Calories.
Pig-iron, slags, and carbon, as above ..	..	..	..	= 653
2.777 ores to 1300 or 800	(average 1050)	$\times 0.23254$	= 323	$\left. \begin{array}{l} \\ \\ \end{array} \right\} = 1093.$
0.010 lime to 1300 or 800	(" 1050)	$\times 0.31940$	= 1	
0.679 coke to 1300 or 800	(" 1050)	$\times 0.31940$	= 116	

For the zone of reduction :

Kils.	Deg.	Deg.	Deg.	Calories.
2.777 ores to 800 or 500 (average			650)	$\times 0.19873 = 165$
0.010 lime to 800 or 500 ("			650)	$\times 0.27624 = 1$
0.679 coke to 800 or 500 ("			650)	$\times 0.26369 = 54$
				$\} = 220.$

Whence the volumes are :

$$\begin{array}{rcl} & \text{Cubic} & \\ & \text{Mètres.} & \\ \text{Of the zone of fusion} & 67.7 & \\ \text{" reduction} & 13.6 & \} = 81.3. \end{array}$$

The reason for this exceedingly small volume of the zone of reduction is the small proportion of slags and coke present, whilst the proportion of oxide of iron is much larger. The volume of the zone of reduction of the blast-furnace at Mägdesprung was 10.753 cubic mètres, and the hourly charge of the furnace on Rachette's system can, therefore, be such as to reduce

$\frac{13.6}{10.753} = 1.265$ times more iron during the same time. This quantity may be doubled by eliminating the nitrogen, whence we get 2.53 times more iron than in the furnace at Mägdesprung. The hourly charge at Mägdesprung contained 94 kils. of iron, and we get, therefore, $2.53 \times 94 = 238$ kils.

Kils.	Kils.	Cubic Mètre.
238 pig-iron correspond with 661 ores	$= \frac{661}{1926}$	$= 0.343$
238 " " 2.4 lime	$= \frac{2.4}{1086}$	$= 0.002$
238 " " 161 coke	$= \frac{161}{400}$	$= 0.4025$
		$\} = 0.7475.$

The time necessary for passing through the zone of reduction would thus be $= \frac{13.6}{0.7475} = 18$ hours and 11 minutes.

Compared with that of the furnace at Mägdesprung, this time is $\frac{18.18}{14.18} = 1.289$ times larger, and we can thus make the hourly charges :

		Cubic Mètres.	
Ores ..	$\frac{661 \times 1.289}{1926}$	$= 0.4424$	}
Lime ..	$\frac{2.4 \times 1.289}{1086}$	$= 0.0027$	
Coke ..	$\frac{161 \times 1.289}{400}$	$= 0.5175$	
			$= 0.9626.$

	Cubic Mètres.
and $\frac{13.6}{0.9626}$	$= 14 \text{ hours } 8 \text{ minutes.}$

By the elimination of the nitrogen, the adoption of a Rachette furnace of the capacity we have supposed and the transferring of the zone of preparation, there would thus be admitted an hourly production of 238 kils. of pig-iron.

If the furnace of Rachette's system had the same capacity as that at Mägdelsprung, the hourly production would be $\frac{238}{1.265} = 188$ kils. against 94 kils. Now, the hourly charges contain 161 kils. of coke = 128.8 kils. of carbon, which will be present as carbonic acid, for example from 536.6 kils. of carbonate of lime, 64.4 kils. of carbon will be absorbed in order to transform the carbonic acid into carbonic oxide.

The necessary quantities of air and carbonic oxide, which have to be introduced per hour, are, 907 kils. and 369.8 kils., quantities which are equal to 701.1 and 295.5 cubic mètres, or, per second, 0.19476 cubic mètre and 0.08279 cubic mètre respectively. The gases discharged per hour at the mouth of the furnace contain 739.7 kils. of carbonic oxide and 685.6 kils. of nitrogen; but as there are absorbed in the zone of reduction, however, about 85 kils. of oxygen, 149 kils. of the existing carbonic oxide are, therefore, transformed into 234 kils. of carbonic acid.

The composition of these gases becomes thus:

Kils.	Cubic Mètres.	
590.7 C O	$= 472.53$	$= 41.56 \text{ per cent.}$
234.0 C O ²	$= 118.98$	$= 10.46 \quad "$
685.6 N	$= 545.62$	$= 47.98 \quad "$
Per hour ..	<u>1137.13</u>	

One cubic mètre of these gases produces $0.4156 \times 3003.6 = 1248$ calories, which corresponds with 0.1664 kil. of pit coal at 7500 calories; and 1137 cubic mètres thus equals 189 kils. of pit coal.

The specific heat of the products of combustion is:

$$\left. \begin{array}{l} \text{C O}^2 \text{ cubic mètre } 0.5202 \times 0.42557 = 0.22138 \\ \text{N} \quad \quad \quad \quad \quad 0.7845 \times 0.30661 = 0.24055 \end{array} \right\} = 0.46198,$$

whence the resulting temperature

$$= \frac{1248}{0.46193} = 2702^{\circ} \text{ C.}$$

If the gas keeps the temperature of 500° till its combustion, it will still contain

$$\left. \begin{array}{l} 0.4156 \times 0.31024 = 0.128940 \\ 0.1046 \times 0.42557 = 0.044515 \\ 0.4798 \times 0.30661 = 0.101070 \end{array} \right\} = 0.274525 \times 500 = 137 \text{ cal.}$$

and the temperature of combustion would in that case be:

$$\frac{1248 + 137}{0.46193} = 2998^{\circ} \text{ C.}$$

These gases are most suitable for use in puddling or reheating furnaces, for they will give a temperature much higher than could be obtained with the best ordinary fire; but the gases would scarcely be sufficient in quantity for more than one reheating furnace, whilst they would be quite sufficient for the preliminary heating of the charges and the introduced gases, for the production of carbonic acid and its transformation into carbonic oxide, and for the generation of the steam necessary for the blowing-engine.

The preliminary heating to 500° of the hourly charges requires:

661 kils. of ores $\times 500 \times 0.16492$..	= 54506	
2.4 „ lime $\times 500 \times 0.23308$..	= 279	
161 „ coke $\times 500 \times 0.18619$..	= 14988	
Latent heat of 52 kils. of water $\times 536.67$	= 27906	
		} = 97679

Calories.

Brought forward

97679

We require a space in the retorts of $0.4 \times 2 = 0.8$ cubic mètre for producing carbonic acid from 536.6 kils. of limestones, occupying a space of 0.4 cubic mètre, whilst the production requires two hours. The reduction of these 236.1 kils. of carbonic acid requires 64.4 kils. of carbon or 80.5 kils. of coke; this carbon being, however, required in excess, and it being more convenient not to have to fill these retorts too frequently, we shall suppose a space in the retorts of 1.6 cubic mètre, containing 640 kils. of coke.

A Silesian zinc furnace, heated with gas, requires for 28 muffles, which have together a capacity of 4.715 cubic mètres, 96 kils. of Silesian pit coal per hour.

$0.8 + 1.6 = 2.4$ cubic mètres of retort capacity, would, therefore, require 49 kils. of that coal, in order to keep the temperature of 1000° ; thus absorbing per hour 49×6607 = 323743

The heating of	$\left\{ \begin{array}{l} = 996.6 \text{ cubic mètres} \\ \text{requires, according to} \\ \text{experience, as a maxi-} \\ \text{mum, } 996.6 \times 100 \text{ ..} \end{array} \right\} =$	99660
701.1 cubic mètres of air		
295.5 " " CO		

The absorption for the generation of the steam for the blowing-engine, with a blast-pressure equal to about 1 centimètre of mercury (Chapter XXXVIII.), will be, according to Chapter XXXVI.:

for $0.19476 + 0.08279 = 0.27755$ cubic mètre of air and gas per second, 1.8 kil. of coals $\times 6500$.. = 11700

The total absorption is, therefore = 532782

Whilst the hourly production of the gas could give

1137 cubic mètres $\times 1248$ = 1418976

Whatever the loss of heat or gas may therefore be, at least half of these gases could be used for other purposes.

CHAPTER XLIV.

DESCRIPTION OF A BLAST-FURNACE FITTED WITH THE NECESSARY APPARATUS FOR THE PARTIAL ELIMINATION OF THE NITROGEN.

IN Plates V. and VI., Fig. 20 represents a vertical section, and Fig. 21 a longitudinal section through the blast-furnace. A is the shaft, B the hearth, *aaa* are the twelve tuyere holes, which are more distinctly shown in the horizontal section at A B, Fig. 22. C is the zone of preparation, and its volume is more than 3 cubic mètres, whilst the volume of the hourly charges is scarcely 1 cubic mètre; the height of the layers of ores and cokes is, therefore, very small in that zone.

The hollow triangular girder D D, made of cast iron, passes through the walls of the furnace, and is open at both ends, thus allowing the air to enter the space C through the apertures *bb*. The movable and horizontal plates *cc* are also provided with apertures *dd*, through which the gas passes directly from the shaft into the space C, where it is consumed together with the air from D. The plates *cc* are provided with racks and pinions, and can therefore be simultaneously raised or lowered by means of the gear *ee*. When the plates are in the position shown in Fig. 21, the space C is closed; but the heated charges fall into the shaft A, as soon as the plates are removed. The apertures *bb* and *dd* must be of sufficient size in order to admit the required quantity of air and gas.

The greater quantity of the gas passes symmetrical through several ports *ff* into the large cast-iron tanks E E, which form also part of the outside platform of the blast-furnace. The object of these tanks is to separate the dust mixed with the gases, and the latter escape then through several pipes F F, placed in the supporting walls G G, in order to diminish the cooling of the gases. A current of cold water is introduced through the tubes *gg* into the box-girders H H, from whence it passes into the water tuyeres *hh*, and then escapes again through the pipes *ii*.

Fig. 23 represents to a larger scale the construction of the air tuyeres K, and of the gas tuyeres L; both tuyeres are fixed vertically, and with an air-tight connection, upon the horizontal conducting pipes K' and L'; and the gas tuyere L is fixed concentrically to the air tuyere K. MM are the flues which serve for the first heating of the furnace, and which are a characteristic of all furnaces on Rachette's system.

In Plate VII., Figs. 24 and 25 represent two sections of furnaces with muffles or with retorts for the generation of carbonic acid from limestone, and for its reduction to carbonic oxide. They are similar to the Silesian zinc furnaces. The burning gases ascend in A, and pass then through the muffles into the flues B, from whence they are drawn away by four flues CC.

The carbonate of lime is decomposed in the muffles D, and the muffles EE are filled with small coals. Both muffles are connected by short tubes *ff*, through which the carbonic acid enters the muffles EE, which are provided near the bottom with a grate for the escape of the carbonic oxide. The latter is carried away through the tubes *hh*. The muffles are closed simply by a thin wall made of a few bricks and moist sand mixed with loam.

Each muffle E is connected by the pipes *hh* with a wash-bottle *i*, which is represented to a larger scale in Fig. 26, in order to show the hydraulic joint with *h* and the accumulating pipe K. The aim of these bottles is only to show at any time to the engineer in charge whether all the muffles are in action, and when the operation is finished.

Each muffle can contain 0.135 cubic mètre of limestone or small coals; and the production necessary for the working, as described in the preceding chapter, requiring 2.4 cubic mètres of retorts or muffles, each furnace must contain $\frac{2.4}{0.135} = 18$ muffles.

Figs. 27 and 28 represent the section and elevation of Fouriet's blowing-engine, which is especially suitable for our purpose, as air as well as gas has to be introduced into the furnace; one of these engines may be used for air and others for the gas; without this arrangement a regulator d. Although these

engines are only single-acting, their dimensions may still be very small, for they have to supply but 0·19476 cubic mètre of air and 0·08279 cubic mètre of gas per second. In order to do without a regulator, at least three of such machines, supplying per second 0·08279 cubic mètre, are required even for the small quantity of gas. The piston of each machine travelling per second 0·5 mètre, the diameter of the cylinder must be 0·375 mètre, which gives 0·0552 cubic mètre of gas per second. About eight of such machines, but of larger diameter, are also required for supplying the necessary air, and there ought to be always one or two more, in order to prevent any interruption of the working in case of accidents or repairing.

Fig. 29 represents an arrangement of the whole plant. A A is the blast-furnace, and B B the apparatus for heating the gas and the air. C C' C'' C''' are four furnaces, each containing 18 muffles. D is the gas-holder, for accumulating the carbonic oxide, which is exhausted from thence by three blowing-machines E E' E'', and forced through the tube *eee* into the heating apparatus B B, from whence it passes into the blast-furnace. The blowing-machines F F' F'' F''' F'''' force the air through the vertical tube *ff* into a pipe similar to *eee*, placed underneath the latter, but introducing the air in the same way into the furnace. G G is the steam-engine for driving the blowing-machines, and H H represent two sets of steam-boilers. The flues *iiii* lead the gases from the mouth of the furnace below the floor to C C' C'' C''' and H H.

APPENDIX.*

THE original German edition of my "Papers relating to the Blast-Furnace" was published two years ago, and although no new facts have been ascertained since that time, the continued study of the subject has nevertheless enlarged my views on many points referred to in the preceding work; and these views are fully explained in the following appendix.

When M. Fiévet—who published the French edition of these papers—wrote to me saying that he had in vain searched the book for instructions how to calculate *a priori* and under modified circumstances the working of any furnace, I was obliged to reply that I acknowledged the want of such information as a defect in the work; but I had found that such a calculation would only be rendered possible by making assumptions which could not be well supported, and that under these circumstances I had thought it much better to omit these assumptions altogether, for the results obtained by their aid might differ very much from the true ones.

I am now, however, very glad to be able to state that these difficulties have been surmounted, and that the values of the many factors involved can thus be shown in a more clear and comprehensive manner.

At first it was impossible to determine *a priori* the quantity of heat lost by the transmission through the walls of the furnace, and these quantities of heat, therefore, could not be taken into consideration for different capacities of the furnace. A chapter in the following appendix now gives this long-desired information.

It is clear that if in one case 2 kils. of fuel are used per kil.

* This Appendix was written by M. Schinz especially for the present edition of his work.

of iron, while in another case only 1.5 kil. of fuel is thus consumed, the quantity of the reducing gases will differ in the same proportion, and this difference must also influence the final result or product. This factor, however, as well as that of the quality of the gases, was formerly not expressed by its numerical value, but it is now given in this appendix.

Another factor omitted in the preceding papers is that representing the free heat which the bodies have to absorb above their point of fusion, by passing through the lower part of the zone of fusion and the zone of gasification.

The contradiction of the statements made by Prof. Mrázek in his article "On the Stöchiometrical Calculation of the Slags of the Blast-Furnace," gave rise to a new investigation of the properties of the materials composing blast-furnace slags; and this investigation resulted in the introduction of a new numerical factor, as explained in the following appendix.

It may be said that the introduction of all these new factors will much complicate the whole theory, but these additions allowed the various factors to be arranged in such a manner as to make an *a priori* calculation possible. The given quantity of fuel on the one side, and the causes of the absorption of heat on the other, form an independent group, by which the result of the calculation is controlled. The result of this group is the time found to be necessary for the passing of the ores through the zone of reduction; it is signified by Z . Now this time must be longer or shorter, according as it is desired to obtain an iron more or less completely reduced by the gases, and if we, therefore, get for Z normal values representing these proportions, the time necessary for the passing of a certain quantity of ores through the zone of reduction, and corresponding with this required value of Z , can thus be found by a simple formula.

This method of *a priori* calculation of the working proportions has made it possible to show also, in a clearer manner, that the elimination of the nitrogen, without any increase in the consumption of fuel, will not only improve the quality of the product, but will also allow a larger quantity of ores to pass during a certain time through the zone of reduction.

In the case of Scotch and similar foundry irons, for example, the production can be increased with a capacity of the furnace of 325 cubic mètres (= 11,480 cubic feet) to the considerable quantity of 1788 kils. of (= 1½ ton) pig-iron per hour.

The elimination of the nitrogen will even allow of the production from ores of an inferior quality of a product almost as good as spiegeleisen, if the necessary oxide of manganese is added; for the elimination effects what is even impossible where charcoal is used, that is to say, it allows a temperature to be given to the zone of fusion just sufficient for smelting the ores, without, however, reducing other bodies which deteriorate the quality of the pig-iron.

CH. SCHINK.

STRASBOURG, January, 1870.

The Transmission of Heat through the Walls of the Furnace.

We gave in Chapter XXIV. the formula—

$$T = \frac{(W_o - W_n) \frac{1}{1 - \frac{s}{w_n}}}{w_n} \left(1 + \frac{p}{B} \right)$$

for calculating the temperature of the zone of gasification; the use of this formula presents, however, a difficulty which formerly was not taken into consideration. The fuel, preliminarily heated, is only partly consumed by the effective combustion, for a part of it is only reduced to CO by the CO² produced, and these two quantities should thus be taken into account separately. But that part of the furnace in which CO² is formed, being of very limited capacity, it is not probable that the half of the fuel in that space really acquires the maximum temperature; should the temperature, however, still be increased, it cannot be of any importance, and will influence more the local than the general temperature of the furnace.

It is thus more rational to calculate simply the temperature

$T = \frac{W_o - W_n}{w n}$ and to multiply the specific heat of the fuel corresponding with this temperature (see Table, Chapter X.) by the weight of the fuel and the temperature T , and to add then the product of the quantity of heat $W_o - W_n$. The sum obtained represents the disposable heat in the furnace, and dividing it by $w n$ we get the initial temperature in the furnace.

Although the formula above given was not used for determining the transmission of heat in Chapter XV., this transmission was still given too high if we consider that the furnace at Clerval is of the old construction, with very thick walls and a square section.

This apparently high transmission is probably due to the circumstance that the descending materials in the furnace absorb free heat above their points of fusion. Of course, this absorption of free heat cannot exactly be proved or calculated, but I have tried to produce a coincidence by calculating many examples under various suppositions, and especially by calculating the transmission of the furnace at Clerval, which I am now able to do much more exactly.

We may thus suppose that the free heat absorbed by the bodies to be smelted is equal to half the difference between the temperature of the point of fusion and the initial temperature, if the former is always taken as a maximum equal to 1300° .

1.1361 kil. of carbon produces in the furnace at Clerval.. ..	Cals. 3183
To these are added, by the preliminary heating of the blast to 180°	279
	<hr/> 3462

The specific heat of the products of combustion is:

$$\left. \begin{array}{l} \text{CO } 2.650 \times 0.248 = 0.657 \\ \text{N } 5.016 \times 0.244 = 1.224 \end{array} \right\} 1.881.$$

$$\text{Therefore } T = \frac{3462}{1.881} = 1840^{\circ},$$

$$\text{And the absorption of heat by the charcoal} = 1.48 \times 1840 \times 0.287 = \quad 782$$

$$\text{Whence the disposable heat} = \quad 4244$$

$$\text{The initial temperature } T' \text{ is then } \frac{4244}{1.881} = 2256^{\circ}.$$

The consumption of heat in the furnace is :

	Kila.	Calories.
Heating of the charcoal	$1.48 \times 0.252 \times 500^\circ = 186$	
" "	$1.48 \times 0.265 \times 500^\circ = 196$	
" " from 1000° to $1840^\circ = 782 - 382 = 400$		
" ores	$2.682 \times 0.186 \times 500^\circ = 249$	
" " from 500° to 800°	$2.682 \times 0.211 \times 300^\circ = 170$	
" limestone	$0.770 \times 0.451 \times 500^\circ = 173$	
" "	$0.770 \times 0.664 \times 300^\circ = 104$	
" { pig-iron from } { 800° to 1000° }	$1 \times 0.130 \times 200^\circ = 26$	
1000° to point of fusion	$1 \times 0.134 \times 200^\circ = 26$	
Heating of { slags from } { 800° to 1000° }	$1.682 \times 0.259 \times 200^\circ = 87$	
From 1000° to point of fusion	$1.682 \times 0.290 \times 300^\circ = 141$	
		1758

Latent heat :

	Kil.	
Pig-iron	1×175	175
Slags	1.682×60	101
Water	1.77×536.67	95
Heat of combination of $C O^2$	0.338×251	85
		456

Carried off by the gases :

	Kila.	
$C O$	$2.650 \times 0.248 = 0.657$	
N	$5.016 \times 0.244 = 1.224$	
$C O^2$	$0.338 \times 0.216 = 0.073$	
$H O$	$1.77 \times 0.475 = 0.841$	
	$2.795 \times 100^\circ =$	279

The excess of temperature attained by the bodies to be smelted :

$$\frac{2256 - 1300}{2} = 478^\circ.$$

Specific heat of these bodies at $1200^\circ \times 478^\circ = 0.154$

" " $1300^\circ \times 478^\circ = 0.359$

therefore :

Pig-iron	$1 \times 0.154 = 0.154$	
Slags	$1.682 \times 0.359 = 0.594$	
	$0.748 \times 478^\circ =$	367
And there remain for transmission		1384
Whence the disposable heat again =		<u>4244</u>

This proportion is in a furnace in the Cleveland district of a	} furnace D.
capacity of 175 cubic mètres = 3·60	
This proportion is in a furnace in Wales for forge iron and	} " E.
of a capacity of 230 cubic mètres = 3·52	
This proportion is in a furnace on Rachette's system of a	} " M.
capacity of 101 cubic mètres = 1·90	
This proportion is in a furnace on Rachette's system of a	} " N.
capacity of 211 cubic mètres = 1·46	
This proportion is in a furnace on Rachette's system of a	} " O.
capacity of 325 cubic mètres = 1·14	

The average inside temperature, to be taken into account for the furnace A, is $\frac{1628 + 750 + 300}{3} = 893^{\circ}$; and the half-initial

temperature = $\frac{2256}{2} = 1128^{\circ}$; but the furnaces B, C, D, and E have thinner walls than the furnace A, and we may, therefore, suppose that the half-initial temperature in these furnaces transmits also 33 per cent. for the unit of surface.

The furnaces B, C, D, E, will thus transmit, if their initial temperature be = $\left. \begin{array}{l} 16\cdot2, 14\cdot3, 11\cdot6, 11\cdot3 \text{ per cent.} \\ 2256^{\circ} \end{array} \right\}$

Or if the initial temperature in the furnace C was, for example, equal to 2600° , the transmission would be

$$\frac{14\cdot3 \frac{2600^{\circ}}{2} \times 33}{1128 \times 33} = 16\cdot5 \text{ per cent.}$$

The transmission for the furnaces on Rachette's system with thicker walls must be reduced in the same proportion as the temperature taken into account increases; if now we take this transmission as equal to 26 per cent., we find that for the initial temperature of 2256° , the furnaces M, N, O, would transmit 4·8, 3·7 and 2·9 per cent.

Or if the initial temperature in the furnace M, for example, is equal to 3381° , we have

$$\frac{4\cdot8 \frac{3381}{2} \times 26}{1128 \times 26} = 7\cdot2 \text{ per cent.,}$$

and with the same initial temperature we should only have for the furnace O

$$\frac{2 \cdot 9 \frac{3381}{2} \times 26}{29228} = 4 \cdot 3 \text{ per cent.}$$

Although these proportions may appear very remarkable to the reader at first sight, they coincide, nevertheless, with experience gained from practice.

A very small furnace charged with charcoal is used, for example, in the neighbourhood of the Eifel, and, producing only 40 kils. of pig-iron per hour, consumes the enormous quantity of 4·5 kils. of charcoal per 1 kil. of the product. It was only a short time ago stated that a furnace of 200 cubic mètres capacity in the Cleveland district consumed 1·525 kil. of fuel per 1 kil. of the product, whilst another furnace of a similar construction, but of a capacity of 400 cubic mètres, consumed only 1·125 kil. per 1 kil. of the product, so that the doubling of the capacity produced a saving of 26·2 per cent. of the fuel.

Of course, the numbers given cannot be said to represent the exact values, but this method of calculation deserves, nevertheless, full confidence, for it gives results, as we have shown, which coincide with experience gained from practice.

The Reductibility of Various Ores and Influence of the Quantity and Quality of the Gases upon the Reduction.

M. Mrázek, Professor of the Imperial School of Mines at Příbram, has published the following method of determining the reductibility of various ores. The proportion of iron contained in the ores which have to be examined is determined by any of the known methods, and any one ore is taken as the base for comparison; we shall recommend for this purpose pure oxide of iron, which, mixed with water only, is easily formed into balls of 8 and 10 millimètres diameter. The ores are next divided into uniform pieces, and so many pieces of each sort which has to be examined are selected, that each group contains an equal quantity of iron. The ores are next placed in a porcelain tube

which is exposed to a moderate heat, and through which a current of a reducing gas is passed.

If Q be taken to represent the weight of the ores selected for the analysis, while q = the weight which has to be deducted for further examination, and f = the iron contained in these ores, the quantity of the reduced iron will be $F = \frac{Qf}{q}$, and the corresponding values of the different ores will thus be represented by $F, F', F'', F''', \&c.$, while the reductibility of the ores will be proportional to these values. If we designate the reductibility of the standard ore (taking as a base for the comparison $Fe^2 O^3$) by $K = 1$ and that of the other ores by $K' K'' K'''$, &c., we get $K' = \frac{F'}{F}$, &c. In order to ascertain the values of $F, F', F'', F''', \&c.$, between $\frac{1}{2}$ and 1 gramme (according to the quantity of reduced iron) is taken of each ore, and after being finely powdered and placed in a test-tube, a solution of sulphate of copper is poured over it. This mixture is next kept in a temperature of 100° during one hour, when the reduced iron is dissolved and metallic copper obtained.

M. Mrázek adopted Parker's and Mohr's method of determining the quantity of copper in the solution, but I think it would have been better to dissolve the residue obtained by decantation, in some nitric acid, and to separate the copper from the filtered and diluted solution by zinc. The quantity of copper obtained in this manner and dried has now only to be multiplied by 0.8927 in order to determine the quantity of the reduced iron contained in the quantity of ore q . Supposing, for instance, we had found 0.202 gramme of iron, and if $Q = 3$ gr., $q = 0.710$ gr., and $f = 1.232$ gr., we should get $F = \frac{3 \times 0.71}{1.232} = 1.73$; if a second trial had given $F' = 1.33$, the reductibility would be $= \frac{F'}{F} = \frac{1.33}{1.73} = 0.676 = K'$.

The application of these coefficients of reduction is very simple, and we shall give an example of it after we have shown

how comparative values can be obtained for the time which it is necessary to allow for the ores to pass through the zone of reduction.

We have seen in Chapter XXI. that the doubling of the volume of gas accelerates the reduction by $\frac{1}{5}$, and as double the weight of fuel produces the double volume of gas, we may simply take the weight of the fuel into account by introducing 1 kil. as the gas-producing unit, and thus simply put for the quantity of fuel $1 + \frac{x-1}{5}$.

If the calculated time for the passage of the ores through the zone of reduction should, therefore, be = 7.3 hours, and if 1.8 kil. of coal were used per 1 kil. of iron, this time would be

$$= Z = 7.3 \times 1 + \frac{1.8-1}{5} = 8.468 = Z'.$$

The time of 7.3 hours refers to the furnace at Seraing, described in Chapter XXVII.; 399 kils. of iron are reduced in the zone of reduction and in the zone of fusion of this furnace, whence the time for the passage of the ores through the zone of reduction for 1000 kils. of iron = $Z' = \frac{1000 \times 7.3}{798 - 309} \times 1 + \frac{1.8-1}{5} = 21.223$.

Putting thus the normal reduction at the normal contents of CO = 1, this reduction is for other proportions, = x , of CO = $1 + (x - 34) \times 0.06817$.

We shall have occasion to apply this formula very often when speaking about the elimination of the nitrogen.

Addition to Chapter XXVIII.

It has often been demonstrated that the quantity, and not the quality, of the slags influences the working of the blast-furnace, but it has also been admitted that basic slags are necessary in order to absorb SO^3 , P O^5 , Si O^3 from the ores. All books on metallurgy speak about slags and charges which are melted either easily or with difficulty, and an increase in the quantity of fuel,

an increase of pressure, or of the temperature, and even special forms of the blast-furnaces, are recommended to remedy the one or the other of these evils, whilst no scientific proof of the success of these propositions is given.

Considering the various methods of working adopted in different districts, the intensity as well as the quantity of the heat produced in the furnace is always found to be much greater than necessary for the liquefaction of the bodies to be smelted, for both ores and slags are heated much above their point of fusion. How can we account under such circumstances for the opinions and observations of practical men?

We fixed the limit of the zone of reduction at 1000° , at which temperature the slags surrounding the iron ores begin to run, and the ores will then only be penetrated by the ascending gases when they arrive at that depth of the furnace where the temperature is sufficient for their liquefaction. It is, however, necessary in order that this layer of half molten slags may descend that the products of combustion may easily pass through, or else, notwithstanding any amount of pressure of blast, no air will any longer enter the furnace, and the combustion would thus be altogether interrupted.

But the question is, not only to prevent this extreme case, but to allow such a quantity of gas to pass through the layer of half molten slags as will correspond with the quantity of ores which have to pass in a given time through the zone of reduction. The height of this layer of half molten slags ought, therefore, to be reduced to a minimum, and this can be effected by enlarging the section of the furnace at the height occupied by this layer. The usual form of the shaft of a furnace is thus justified, if this layer of half molten slags really occupies the wide part of the furnace, a matter which, of course, depends entirely upon the manner in which the furnace is worked; it will, therefore, be of great advantage to be able to calculate *a priori* the exact position of this layer.

Now, those ores which contain manganese in large quantities are especially considered to be easily fusible, for the manganese cannot be reduced at the temperature of the zone of reduction, and being, therefore, added to those materials forming the slags, and

accelerating consequently the fusion of the latter, it must facilitate the descent of the layer of still half molten slags and the passage through that layer of the gases of combustion.

The Calculation, a priori, of the Effects of Different Methods of working a Furnace.

By means of the method, given above, of reducing the time necessary for the passage of the ores through the zone of reduction to a normal amount, we are able to compare the different methods of working with each other. In order to do this, and thus get a scale for the effect of the reduction and carburization of the iron, we shall compare the working of the furnaces in different districts; we shall take at first the working at Lowmoor, which is considered to be best for the *quality*; next, the working of the furnaces in Wales and the Cleveland districts for the production of foundry pig-iron; and finally, that adopted in Wales for the production of large *quantities* of forge-pig. The different examples are indicated by B, C, D, and E.

B.

The production of heat in a Lowmoor furnace is, without hot blast, from 2 kils. of fuel (not having more exact statements, we take the fuel as being = 80 per cent. carbon):

$$1.6 C = \frac{1.6}{2} \times 5600 = 4480 \text{ calories.}$$

$$\text{Specific heat of pro-} \left\{ \begin{array}{l} 3.733 CO \times 0.248 = 0.926 \\ \text{ducts of combustion: } 7.068 N \times 0.248 = 1.724 \end{array} \right\} 2.650,$$

whence $T = \frac{4480}{2.650} = 1691^\circ$, which temperature is increased by

preliminary heating of the fuel to $2.6 \times 1691 \times 0.467 = 1578$ calories; or the disposable heat = $4480 + 1578 = 6058$ calories,

$$\text{whence: } T^1 = \frac{6058}{2.650} = 2286^\circ,$$

$$\text{and the transmission} = \frac{16.2 \times \frac{2286}{2} \times 33}{37224} = 16.4 \text{ per cent.} =$$

993 calories; while the temperature of the bodies to be smelted above that of the point of fusion = $\frac{2286 - 1300}{2} = 493^{\circ}$.

The charges contain per kil. of pig-iron: 2·579 kils. of ores, 1 kil. of limestone, 2·139 kils. of slags from ores and limestone, and 2·539 kils. of fuel, inclusive of ashes.

C.

For the production of a similar but less pure pig-iron, there are used in Wales: 1·6 kil. of coals = 1·28 C; 1·369 kil. of ores; 1 kil. of limestone, and 0·929 kil. of ores and limestones for slags.

The ores are richer than those used at Lowmoor; the quantity passing through the zone of reduction per hour is 750 kils. Fe, which gives per cubic mètre of the capacity of the furnace $\frac{750}{110} = 6·8$ kils., whilst the proportion at Lowmoor is only $\frac{417}{65} = 6·4$ kils.

This difference is perhaps due to the greater richness of the ores in the former case, but if we consider that with B the quantity of the gases that passes through per hour is equal to $417 \times 10·801 = 4504$ kils., whilst the quantity for the example C is $750 \times 8·488 = 6326$ kils., we may assume that the passage of this quantity through the slags has been facilitated by the addition of Fe O, for which we shall take 0·1 of the iron transformed into slags, which requires for its direct reduction 0·022 C.

We have thus to deduct 0·022 C from 1·28 C, and get 1·258 C, which give $0·5 \times 1·258 \times 5600 = 3522$ calories
less $0·022 \times 2400 = 53$ „

3469 „

but we have to add for the hot blast 7·021 kils.

of air $\times 0·2377 \times 330^{\circ}$ = 541 „

4010 „

The specific heat of the products of combustion is :

$$\left. \begin{array}{l} \text{CO } 3.103 \times 0.248 = 0.771 \\ \text{N } 5.875 \times 0.244 = 1.437 \end{array} \right\} 2.208, \text{ and } T = \frac{4112}{2.208} = 1862^{\circ};$$

$$\text{while } T' = \frac{5774}{2.208} = 2615^{\circ}, \text{ whence transmission} =$$

$$\frac{14.3 \times \frac{2615}{2} \times 33}{37224} = 16.6 \text{ per cent.} = 958 \text{ calories, and free}$$

$$\text{heat} = \frac{2615 - 1300}{2} = 657^{\circ}.$$

E.

We are not troubled in this case with the question of how much iron passes into the slags, for so much forge and finery cinder is added to the charges, that a considerable quantity of FeO remains with the slags in an unreduced state; we suppose, therefore, that one-third of the iron is reduced in the zone of reduction, and get thus :

$$\begin{array}{rcl} 1.5 \text{ kil. of coals} & = 1.2 \text{ C} - 0.071 & = 1.129 \text{ C,} \\ \text{and } 0.5 \times 1.129 \times 5600 & \dots \dots \dots & = 3158 \text{ calories} \\ \text{less } 0.071 \times 2400 & & = 171 \quad \text{,,} \\ \hline & & 2987 \quad \text{,,} \end{array}$$

There is added by the hot blast :

$$6.492 \times 0.2377 \times 330^{\circ} \dots \dots \dots = 509 \quad \text{,,}$$

And by the preliminary heating of the fuel :

$$1.5 \times 1870^{\circ} \times 0.496 \dots \dots \dots = 1391 \quad \text{,,}$$

$$\text{Disposable heat} = 4887 \quad \text{,,}$$

The specific heat of the products of combustion is :

$$\left. \begin{array}{l} \text{CO } 2.634 \times 0.248 = 0.653 \\ \text{N } 4.987 \times 0.244 = 1.217 \end{array} \right\} 1.870;$$

$$\text{whence } T = \frac{3496}{1.870} = 1870^{\circ}, \text{ and } T' = \frac{4887}{1.870} = 2613^{\circ}.$$

$$\text{Transmission} = \frac{11.3 \times \frac{2613}{2} \times 33}{37224} = 13.1 \text{ per cent.} = 640 \text{ cal.}$$

$$\text{Free heat} = \frac{2613 - 1300}{2} = 606^\circ.$$

The following Table gives the data derived from the calculations and statements we have made in reference to B, C, D, D', and E; and it also gives the volumes of the charges, the time necessary for their reduction, and finally the volumes of the

Disposal of Heat in the Furnaces.			No.	B.	C.
Preliminary heating of the					
Fuel	from	0 to 500	1	2' $\times 0.254 \times 500^\circ$	= 254 1.6 $\times s \times 500^\circ$ =
"	"	500 " 1000	2	2' $\times 0.331 \times 500$	= 331 1.6 $\times s \times 500$ =
			3	1578 - 585	= 993 1570 - 452 =
Ores	"	0 " 500	4	2.579 $\times 0.186 \times 500$	= 240 1.369 $\times s \times 500$ =
"	"	500 " 800	5	2.579 $\times 0.211 \times 300$	= 163 1.369 $\times s \times 500$ =
Limestone	"	0 " 500	6	1' $\times 0.451 \times 500$	= 225 1' $\times s \times 500$ =
"	"	500 " 800	7	1' $\times 0.664 \times 300$	= 199 1' $\times s \times 300$ =
Pig-iron	"	800 " 1000	8	1' $\times 0.130 \times 200$	= 26 1' $\times s \times 200$ =
"	"	1000 " point of fusion	9	1' $\times 0.134 \times 200$	= 27 1' $\times s \times 200$ =
Slags	"	800 " 1000	10	2.139 $\times 0.259 \times 200$	= 111 0.929 $\times s \times 200$ =
"	"	1000 " 1300	11	2.139 $\times 0.297 \times 300$	= 190 0.929 $\times s \times 300$ =
Latent heat of the					
Pig-iron	..	.. ..	12	1' $\times 175$	= 175 1' $\times 175$ =
Slags	..	.. ..	13	2.539 $\times 60$	= 152 1.304 $\times 60$ =
Water in the fuel	..	.. ..	14	0.1 $\times 536$	= 53 0.1 $\times 536$ =
Heat of combination of the CO ²	..	.. ..	15	0.44 $\times 251$	= 110 0.44 $\times 251$ =
Carried off by waste gases ..					
			16	CO + N = 0.926	2.925 $\times 0.248 = 0.733$
				N = 1.724	5.554 $\times 0.244 = 1.355$
				CO ² = 0.095	0.44 $\times 0.216 = 0.095$
				HO = 0.047	0.1 $\times 0.475 = 0.047$
Free heat of Fe					
			17	1 Fe $\frac{1.792 \times 697^\circ}{0.168} = 1250$	2.230 $\times \frac{483^\circ}{0.161} =$
"	slags	.. ..		2.539 $\times 0.386 = 0.980$	1.304 $\times 0.378 = 0.493$
Transmission					
			18	$\frac{493 \times 1.148^\circ}{993} = 566$	0.654 $\times \frac{650^\circ}{993} =$
				6058	

The specific heat of the products of combustion is :

$$\left. \begin{array}{l} \text{CO} = 2.934 \times 0.248 = 0.728 \\ \text{N} = 5.554 \times 0.244 = 1.355 \end{array} \right\} 2.083, \text{ whence } T = \frac{4010}{2.083} = 1950^\circ.$$

The preliminary heating of the fuel adds $1950 \times 1.6 \times 0.515 = 1406$ calories, whence the disposable heat is equal to

$$4010 + 1406 = 5416 \text{ calories.}$$

The temperature T' is, therefore, $= \frac{5416}{2.083} = 2600^\circ$, and the

$$\text{transmission.} = \frac{14.3 \times \frac{2600}{2} \times 33}{37224} = 16.5 \text{ per cent.} = 893 \text{ cal.}$$

The difference between the temperature of the bodies to be smelted and that of the point of fusion $= \frac{2600 - 1300}{2} = 650^\circ$.

The gases $\left\{ \begin{array}{l} \text{CO} = 2.959 \text{ kils.} = 2.364 \text{ vols.} = 34.8 \text{ per cent.} \\ \text{N} = 6.554 \text{ ,,} = 4.420 \text{ ,,} = 65.2 \text{ ,,} \end{array} \right.$

D.

The consumption of coke per kil. of pig-iron in the Cleveland district is equal to 1.8 kil.* for foundry iron, and the charges contain for the same unit, 2.01 kils. of ores, 1 kil. of limestone, and 1.57 kil. of material for slags, and 1.903 kil. of fuel, inclusive of ashes. Knowing of no analyses of the gases from the mouth of the furnace, we can only assume how much un-reduced iron passes into the zone of fusion; we shall make two suppositions, and shall afterwards see which one gives the more probable result. According to the first supposition one-third of the ores is directly reduced, while, according to the second supposition, the reduction of one-half of the ores is thus effected. *In the first case we get :*

$$\begin{array}{l} 1.8 \text{ kil. of coke} = 1.44 \text{ C, less } 0.053 \text{ for direct reduction,} \\ \text{or } 1.387 \text{ kil. of C} \times 0.5 \times 5600 = 3881 \text{ calories.} \\ \text{less } 0.053 \times 2400 = 127 \text{ ,,} \end{array}$$

$$\text{Carried forward 3754 ,,}$$

* This allowance is somewhat excessive.—TRANSLATORS.

Brought forward	3754 calories.
But there is added by means of the hot blast	
7.976 kils. of air $\times 0.2377 \times 350^\circ$..	= 652 ..
	<hr/> 4406 ..
And by the preliminary heating of the fuel	
in the shaft of the furnace $1.8 \times 1918^\circ$	
$\times 0.506$	= 1747 ..
	<hr/> Disposable heat = 6153 ..

The specific heat of the products of combustion is :

$$\left. \begin{array}{l} \text{CO} = 3.236 \times 0.248 = 0.802 \\ \text{N} = 6.127 \times 0.244 = 1.495 \end{array} \right\} 2.297, \text{ whence } T = \frac{4406}{2.297} = 1918^\circ,$$

$$\text{and } T' = \frac{6153}{2.297} = 2607^\circ.$$

The transmission is $\frac{14.3 \times \frac{2607}{2} \times 33}{37224} = 13.8$ per cent. = 849 calories; and the height of the temperature above that of the point of fusion of the bodies to be smelted

$$\frac{2607 - 1800}{2} = 653^\circ.$$

D'. In the second case we get:

1.44 C — 0.107 C = $1.333 \times 0.5 \times 5600$	= 3732 calories
— 0.107×2400	= 257 ..
	<hr/> 3475 ..
Added by hot blast $7.665 \times 0.2377 \times 350^\circ$	= 637 ..
	<hr/> 4112 ..
And by the preliminary heating of the fuel	
$1.8 \times 1862^\circ \times 0.496$	= 1662 ..
	<hr/> Disposable heat = 5774 ..

different zones, and the times occupied by the charges in passing through them. In columns C, D, and E, the factor s has values equal the corresponding multipliers in column B.

The high temperatures obtained show that we have probably considered the charges to be much drier than they are in reality, for we have not considered the quantity of water contained in the blast, in order not to complicate the calculation uselessly. We have, however, already shown in Chapter V. that the saturation of the blast with moisture may produce a difference of the temperature of $1740 - 1441 = 299^{\circ}$.

Comparing now the results obtained with each other, we get

D.		E.		D ¹ .	
	Cala.		Cala.		Cala.
$\frac{1}{2} \times s \times 500^{\circ}$	= 210	$\frac{1}{2} \times s \times 500^{\circ}$	= 175		210
$\frac{1}{2} \times s \times 500$	= 298	$\frac{1}{2} \times s \times 500$	= 248		298
47-508	= 1239	1391-423	= 968	1662-508	1154
11 $\times s \times 500$	= 187	1.33 $\times s \times 500$	= 123		187
11 $\times s \times 300$	= 127	1.33 $\times s \times 500$	= 84		127
$\times s \times 500$	= 225	0.85 $\times s \times 500$	= 191		225
$\times s \times 300$	= 199	0.85 $\times s \times 300$	= 169		199
$\times s \times 200$	= 26	1. $\times s \times 200$	= 26		26
$\times s \times 200$	= 27	1. $\times s \times 50$	= 6		27
7 $\times s \times 200$	= 81	0.806 $\times s \times 200$	= 42		81
7 $\times s \times 300$	= 141	0.806 $\times s \times 300$	= 72		141
$\times 175$	= 175	1. $\times 139$	= 139		175
03 $\times 60$	= 116	1.146 $\times 60$	= 69		116
$\times 536$	= 53	0.1 $\times 536$	= 53		53
4 $\times 251$	= 110	0.347 $\times 251$	= 94		110
25 } $\times 0.248 = 0.807$	0.165 }	$\times 0.248 = 0.694$	0.250 }	$\times 0.248 = 0.831$	
36 }	2.634 }		3.103 }		
27 $\times 0.244 = 1.495$	4.987	$\times 0.244 = 1.217$	5.875	$\times 0.244 = 1.437$	
$\times 0.216 = 0.095$	0.347	$\times 0.216 = 0.081$	0.44	$\times 0.216 = 0.081$	
$\times 0.475 = 0.047$	0.1	$\times 0.475 = 0.047$	0.1	$\times 0.475 = 0.047$	
$2.444 \times 604^{\circ} = 1475$		$2.039 \times 690^{\circ} = 1407$		$2.396 \times 506^{\circ} = 1097$	
0.166		0.203			
13 $\times 0.385 = 0.732$	1.146	$\times 0.372 = 0.426$			
$0.898 \times 685^{\circ} = 615$		$0.629 \times 606^{\circ} = 381$		$\times 0.898 \times 657^{\circ} = 590$	
849		640		958	
6153		4887		5774	

	B.	C.																																																																						
Hourly charges—																																																																								
Contents of Fe .. =	417 kilogrammes.	750 kilogramm																																																																						
Coals or coke	$\frac{843}{400} = 2.085$ cub. mè.	$\frac{1200}{600} = 2.000$ cu																																																																						
Ores	$\frac{1075}{2060} = 0.522$ „	$\frac{1027}{2060} = 0.498$																																																																						
Hematite																																																																						
Refinery and forge cinder																																																																						
Limestone	$\frac{417}{2200} = 0.347$ cub. mè.	$\frac{750}{1200} = 0.625$ cul																																																																						
Volume of the hourly charge	2.954 „	3.123																																																																						
Capacity of the furnace ..	65 „	110																																																																						
Time required per charge for passing through the furnace }	$\frac{65}{2.954} = 22$ hours.	$\frac{110}{3.123} = 35.2$ h																																																																						
Absorption of heat, which has an influence upon the volumes of the zones ..	<table><tr><td>No.</td><td>cal.</td><td>No.</td><td>cal.</td><td>No.</td><td>cal.</td></tr><tr><td>3 =</td><td>993</td><td>2 =</td><td>331</td><td>1 =</td><td>254</td></tr><tr><td>9 =</td><td>27</td><td>5 =</td><td>163</td><td>4 =</td><td>240</td></tr><tr><td>11 =</td><td>190</td><td>7 =</td><td>199</td><td>6 =</td><td>225</td></tr><tr><td></td><td></td><td>8 =</td><td>26</td><td></td><td></td></tr><tr><td>17 =</td><td>566</td><td>10 =</td><td>111</td><td></td><td></td></tr><tr><td></td><td>1776</td><td></td><td>830</td><td></td><td>719</td></tr></table>	No.	cal.	No.	cal.	No.	cal.	3 =	993	2 =	331	1 =	254	9 =	27	5 =	163	4 =	240	11 =	190	7 =	199	6 =	225			8 =	26			17 =	566	10 =	111				1776		830		719	<table><tr><td>No.</td><td>cal.</td><td>No.</td><td>cal.</td></tr><tr><td>3 =</td><td>1118</td><td>2 =</td><td>265</td></tr><tr><td>9 =</td><td>27</td><td>5 =</td><td>299</td></tr><tr><td>11 =</td><td>83</td><td>7 =</td><td>199</td></tr><tr><td></td><td></td><td>8 =</td><td>26</td></tr><tr><td>17 =</td><td>425</td><td>10 =</td><td>48</td></tr><tr><td></td><td>1653</td><td></td><td>837</td></tr></table>	No.	cal.	No.	cal.	3 =	1118	2 =	265	9 =	27	5 =	299	11 =	83	7 =	199			8 =	26	17 =	425	10 =	48		1653		837
No.	cal.	No.	cal.	No.	cal.																																																																			
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17 =	425	10 =	48																																																																					
	1653		837																																																																					
Proportionate volume of the zones of fusion and gasi- fication	34.72 cubic mètres.	60.03 cubic mèl																																																																						
Proportionate volume of the zone of reduction	16.22 „	30.39 „																																																																						
Proportionate volume of the zone of preparation	14.06 „	19.58 „																																																																						
	65.00 „	110.00 „																																																																						
Corresponding time necessary for the passage of the charges through the zones of fusion and gasification .	11.75 hours.	19.21 hours.																																																																						
Corresponding time neces- sary for the passage of the charges through the zone of reduction	5.49 „	9.72 „																																																																						
Corresponding time neces- sary for the passage of the charges through the zone of preparation	4.76 „	6.27 „																																																																						
	22.00 „	35.20 „																																																																						
Initial temperatures in the zone of fusion		2600°																																																																						

	D.			D ¹ .			E.		
	1042 kilogrammes.			1042 kilogrammes.			1833 kilogrammes.		
K	$\frac{1875}{400} = 4.687$ cubic mètres.			4.687 cubic mètres.			$\frac{2749}{600} = 4.581$ cub. mètr.		
	$\frac{2096}{2060} = 1.016$ "			1.016 "			$\frac{2016}{2060} = 0.978$ "		
	.. ..			.. ..			$\frac{1466}{4000} = 0.366$ "		
	.. ..			.. ..			$\frac{916}{1800} = 0.509$ "		
K	$\frac{1042}{1200} = 0.868$ cubic mètr.			0.868 cubic mètr.			$\frac{1558}{1200} = 1.298$ "		
	$\frac{6.571}{175}$ "			$\frac{6.571}{175}$ "			$\frac{7.672}{230}$ "		
	$\frac{175}{6.571} = 26.6$ hours.			$\frac{175}{6.571} = 26.6$ hours.			$\frac{230}{7.672} = 30$ hours.		
	No. cal. No. cal. No. cal.			No. cal. No. cal. No. cal.			No. cal. No. cal. No. cal.		
	8=1239	2=298	1=210	3=1240	2=298	1=210	3= 968	2=248	1=174
	9= 27	5=127	4=187	9= 27	5=127	4=187	9= 6	5= 84	4=124
	11= 141	7=199	6=225	11= 141	7=199	6=225	11= 72	7=169	6=191
		8= 26			8= 26			8= 26	
	17= 615	10= 81		17= 590	10= 81		17= 381	10= 42	
	1022	731	622	1998	731	622	1427	569	484
	104.85 cubic mètres.			104.34 cubic mètres.			132.08 cubic mètres.		
	37.90 "			38.17 "			52.66 "		
	32.25 "			32.49 "			45.26 "		
	175.00 "			175.00 "			230.00 "		
	15.94 hours.			15.86 hours.			17.23 hours.		
	5.76 "			5.80 "			6.87 "		
	4.90 "			4.94 "			5.90 "		
	26.60 "			26.60 "			30.00 "		
	2607°			2615°			2613°		

the time, Z , necessary for the passage of the charge through the zone of reduction :

$$\text{In B. } Z = \frac{1000 \times 5.49}{417} \times \left(1 + \frac{2-1}{5}\right) = 15.799 \text{ hours.}$$

$$\text{„ C. } Z = \frac{1000 \times 9.72}{750-75} \times \left(1 + \frac{1.6-1}{5}\right) = 16.128 \text{ „}$$

$$\text{„ D. } Z = \frac{1000 \times 5.76}{1042-347} \times \left(1 + \frac{1.8-1}{5}\right) = 9.470 \text{ „}$$

$$\text{„ D'. } Z = \frac{1000 \times 5.80}{1042-541} \times \left(1.088 + \frac{1.8-1}{5}\right) = 12.401 \text{ hrs.}$$

$$\text{„ E. } Z = \frac{1000 \times 6.87}{1833-916} \times \left(1.068 + \frac{1.5-1}{5}\right) = 8.241 \text{ „}$$

These values of Z , upon which the final success of the working of the furnace after all depends, will enable us to calculate even *a priori* the proportions of any other system.

Considering the capacity of the shaft of the furnace in example D, the quantity of the charge that passes in the unit of time through the zone of reduction appears to be remarkably small; but that depends evidently upon the quality of the slag-forming materials, which consist of:

	$\text{Si O}^2 = 0.506 =$	0.270
	$\text{P O}^2 = 0.097 =$	0.055
	$\text{S} = 0.004 =$	0.004
	$\text{Al}^2 \text{O}^3 = 0.480 =$	0.244
inclusive of }	$\text{Ca O} = 0.697 =$	0.199
limestone }	$\text{Mg O} = 0.136 =$	0.054

whence the proportion between } $0.329 : 0.497 = 0.66:1.$
the acid and basic oxygen is }

This proportion is evidently too basic, and more Si O^2 is required; and notwithstanding the large quantity of Fe O in the zone of fusion, such a mixture cannot be easily liquefied, for the Fe O renders the mixture still more basic, and takes from

the Al_2O_3 , MgO , and CaO , the SiO_2 , which ought to facilitate the liquefaction.

An addition of forge cinder could not remain without effect, for the PO_2 which these slags contain in considerable quantities is less injurious to the quality of foundry pig-iron than to that of forge iron, from which it is difficult to eliminate the P.

There are in various parts of the world still many ores regarded as of scarcely any value, because they contain chiefly $\text{FeO} + \text{SiO}_2$; but these ores are generally poor in PO_2 , and would, therefore, be the best substitute for forge cinder, when forge pig is to be produced at a very cheap price.

We shall now investigate the working as given for the furnace E, but shall substitute for the forge and refinery cinder those ores from Wales, which contain much $\text{FeO} + \text{SiO}_2$; the furnace is supposed to be the same as that designated by N in the Appendix to Chapter XV. We shall commence by determining the quantity of fuel required.

Coals	1.2	1.25	1.3	1.35	1.4	1.45	1.5	1.55
Containing carbon ..	0.96	1.00	1.04	1.08	1.12	1.16	1.20	1.24
Of which are required for the direct reduction of Fe	0.026	0.026	0.026	0.026	0.026	0.026	0.026	0.026
Whence remains for combustion	C 0.934	0.974	1.014	1.044	1.094	1.134	1.174	1.214
The specific heat of the products of combustion is	CO 0.540 N 1.007	0.563 1.050	0.586 1.093	0.603 1.125	0.632 1.180	0.655 1.222	0.678 1.265	0.701 1.308
	1.547	1.613	1.679	1.728	1.812	1.877	1.943	2.009
Heat produced by the remaining C .. =	Cals. 2615	Cals. 2727	Cals. 2839	Cals. 2923	Cals. 3063	Cals. 3175	Cals. 3287	Cals. 3399
But the 0.026 kil. C absorbs for direct reduction	52	52	52	52	52	52	52	52
Whence remain ..	2563	2675	2787	2871	3011	3123	3235	3347
The temperatures of combustion are ..	1657°	1658°	1659°	1661°	1662°	1664°	1665°	1666°
Added by coke (spec. heat = 0.457) ..	884	922	961	990	1038	1078	1116	1155
Disposable heat ..	Cals. 3447	Cals. 3597	Cals. 3748	Cals. 3861	Cals. 4049	Cals. 4201	Cals. 4351	Cals. 4502
Resulting initial tem- peratures	2228°	2230°	2232°	2234°	2235°	2236°	2238°	2241°

The heat added by the coke is that formerly absorbed by it, but set free by the combustion; the quantity of this heat is obtained by multiplying the temperature of combustion by the weight of the coke and the specific heat at this temperature.

The transmission is calculated from the initial temperature,

$$\text{as for example for the furnace N} = \frac{3.7 \times \frac{2228}{2} \times 26}{29228} = 3.7 \text{ per}$$

cent. of the disposable heat, and it remains the same for these numbers, which differ very little from those for the furnace N. The average value of the heat absorbed by the charges may also be taken = $\frac{2234 - 1300}{2} = 467^\circ$. The specific heat of the iron at 467° above the point of fusion = 1517° is = 0.184 , and that of the slags at 1767° = 0.353 ; whence

$$1. \text{ Fe} \quad 0.184$$

$$1.189 \text{ slags} = 0.419$$

$$0.603 \times 467^\circ = 281 \text{ calories.}$$

We get:

For the quantities of coke consumed	1.2	1.25	1.3	1.35	1.4	1.45	1.5	1.55
	Cals.	Cals.	Cals.	Cals.	Cals.	Cals.	Cals.	Cals.
The transmission	127	133	138	143	150	155	161	166
The free heat absorbed by the ores	281	281	281	281	281	281	281	281
Free heat absorbed by coke and charges ..	1844	1882	1921	1950	1998	2038	2076	2115
Total heat absorbed ..	2252	2296	2340	2374	2429	2474	2518	2562
Against disposable heat	3447	3597	3748	3861	4049	4201	4351	4502
Difference = evacuation	1195	1301	1408	1487	1620	1727	1833	1940

Absorption by coke and charges is:

		No.							
Coke ..	$1.2 \times 0.234 \times 500^\circ = 1,$	140	146	152	158	164	169	175	181
" ..	$1.2 \times 0.331 \times 500^\circ = 2,$	198	206	214	222	231	239	247	256
Total quantity, less Nos. 1 and 2 = 3,	546	570	595	610	643	670	694	718	
Carried forward ..	884	922	961	990	1038	1078	1116	1155	

	Brought forward	No.	884	922	961	990	1038	1078	1116	1155
Dres ..	$1.503 \times 0.186 \times 500^\circ =$	4, 140								
" ..	$1.503 \times 0.211 \times 300^\circ =$	5, 95								
Limestone	$0.6 \times 0.415 \times 500^\circ =$	6, 135								
"	$0.6 \times 0.664 \times 300^\circ =$	7, 119								
Iron ..	$1 \times 0.130 \times 200^\circ =$	8, 26								
" ..	$1 \times 0.134 \times 50^\circ =$	9, 6								
Slags ..	$0.839 \times 0.759 \times 200^\circ =$	10, 43								
" ..	$0.839 \times 0.299 \times 300^\circ =$	11, 75								
Latent heat of iron	1.139	$= 12, 139$								
" ..	slags 1.189×60	$= 13, 71$								
" ..	water 0.1×536	$= 14, 53$								
Heat of combination	$CO^2 =$	$\} = 15, 58$								
0.234×251	.. .. .								
Absorbed by coke and charges as stated above	.. .. .	$\}$	1844	1882	1921	1950	1998	2038	2076	2115

But the temperature of all the waste gases is still too high, and we find it by adding 0.097 for the additional carbonic acid and vapour, and by dividing the waste heat by the sum thus obtained. We have thus :

$$727^\circ, 761^\circ, 792^\circ, 815^\circ, 849^\circ, 875^\circ, 898^\circ, 921^\circ.$$

The moisture in the blast, which has not been taken into account, has evidently increased these temperatures, and 3.303 kils. of the materials charged will seldom contain as little as 3 per cent. of water. We shall, therefore, suppose that these causes of the depression of the temperature of waste gases restore the normal proportion, and shall now examine the proportion between the time required for the charges to pass through the zones of fusion, gasification, reduction, and preparation, and the volumes of these zones :

	The heat absorbed in the zones of fusion and gasification is	..	..	..	No.	3=	546	570	595	610	643	670	694	718
						9=	6							
						11=	75							
Free heat	..	17=	281					362	362	362	362	362	362	362
								908	932	957	972	1005	1032	1056
								1080						

	No.								
In the zone of reduction	2 = 198	206	214	222	231	239	247	256	
	5 = 95								
	7 = 119								
	8 = 26	283	283	283	283	283	283	283	
	10 = 43								
		481	489	497	505	514	522	530	539
In the zone of preparation	1 = 140	146	152	159	164	169	175	181	
	4 = 140								
	6 = 135	275	275	275	275	275	275	275	
		415	421	427	434	439	444	450	456
In all the zones together		1804	1842	1881	1911	1958	1998	2036	2075

Putting now both volume and time required by the charges for passing through the zones, equal to 1, we get :

Zone of gasification and fusion	0.503	0.506	0.509	0.509	0.513	0.517	0.519	0.520
Zone of reduction	0.267	0.265	0.264	0.264	0.263	0.261	0.260	0.260
Zone of preparation	0.230	0.229	0.227	0.227	0.224	0.222	0.221	0.220

The volume of the zone of fusion increases, therefore, with the quantity of fuel, whilst the volumes of the zones of reduction and preparation decrease in the same proportion.

Of course the decrease in the volume of the zone of reduction is more than compensated for by the quantity of gas, which increases with the increased consumption of fuel the more the transmission of the furnace is diminished. We have to multiply in that case the values obtained by

$$1 + \frac{1.2 - 1}{5}; 1 + \frac{1.25 - 1}{5}; 1 + \frac{1.3 - 1}{5}; 1 + \frac{1.35 - 1}{5};$$

$$1 + \frac{1.40 - 1}{5}; 1 + \frac{1.45 - 1}{5}; 1 + \frac{1.5 - 1}{5}; 1 + \frac{1.55 - 1}{5};$$

and we get :

$$0.277; 0.278; 0.280; 0.282; 0.282; 0.292; 0.286; 0.288.$$

This value increases, therefore, until the consumption is 1.45,

but it decreases afterwards, and we thus have to accept the consumption of 1.45 kil. of coke as the most advantageous one.

In order to ascertain now what charge can under those circumstances pass through the furnace during the unit of time, we shall suppose this charge to be = 1000 Fe; the composition and volume of the hourly charge will then be :

$$\begin{array}{lcl}
 1.45 \times 1000 = 1450 \text{ coke} & \dots = \frac{1450}{400} = 3.625 \text{ cubic mètres} & \\
 1.503 \times 1000 = 1503 \text{ ores} & \dots = \frac{1503}{2060} = 0.729 \text{ " " } & \\
 0.334 \times 1000 = 334 \text{ hematite} & \dots = \frac{334}{4000} = 0.083 \text{ " " } & \\
 0.208 \times 1000 = 208 \text{ silicious ores} & \dots = \frac{208}{3000} = 0.069 \text{ " " } & \\
 0.6 \times 1000 = 600 \text{ limestone} & \dots = \frac{600}{1200} = 0.500 \text{ " " } &
 \end{array}
 \left. \vphantom{\begin{array}{l} 1.45 \\ 1.503 \\ 0.334 \\ 0.208 \\ 0.6 \end{array}} \right\} 5.006 \text{ cubic mètres.}$$

whence the time required by the charge for passing through the furnace N of a capacity of 211 cubic mètres = $\frac{211}{5.006} = 42.15$ hours, or the time required for passing through the zone of reduction, that is to say Z, = $42.15 \times 0.292 = 12.308$ hours. This value is considerably greater than that obtained for the example E, which gave only 8.241 (see page 216). The question is now to find what charge corresponds with the value $Z^1 = 8.241$.

We shall use for that purpose the formula

$$x^2 = \frac{\frac{M}{2G} \times \frac{V}{M} \cdot 1000}{x F} \times m = \frac{V \cdot 1000 \cdot m}{x^2 G F};$$

in which

M = capacity of the furnace.

V = volume of the zone of reduction; in the present case
 $0.261 \times 211 = 55.071$ cubic mètres.

F = weight of the iron reduced in the zone of reduction; in
the present case = $1000 - 121 = 879$.

G = volume of the hourly charge = $5 \cdot 006$.

m = reduction increased by the quality and quantity of the

$$\text{gases} = 1 + \frac{1 \cdot 45 - 1}{5} = 1 \cdot 09.$$

x^2 = number, by which the supposed charge (= 1000) has to be multiplied, in order to obtain the value $Z = 8 \cdot 24$.

We have :

$F = \log. 2 \cdot 94399$	$\log. V = 1 \cdot 74092$	$\left. \begin{array}{l} \text{After substituting different values we find for } x = 1 \cdot 286. \end{array} \right\}$
$G = \text{,, } 0 \cdot 69949$	$m \times 100 = 3 \cdot 03742$	
<u>3 \cdot 64348</u>	<u>4 \cdot 77834</u>	
$x^2 = \text{,, } 0 \cdot 21848$	<u>-3 \cdot 86196</u>	
<u>3 \cdot 86196</u>	$\log. 0 \cdot 91638 = 8 \cdot 2486$	

The hourly charges are, therefore,

$1 \cdot 286 \times 1 \cdot 45 \times 1000 = \text{coke}$	$\dots = 1865$	and $\frac{1865}{400} = 4 \cdot 662$	$\left. \begin{array}{l} 6 \cdot 439 \\ \text{cubic} \\ \text{mètres.} \end{array} \right\}$
$1 \cdot 286 \times 1 \cdot 503 \times 1000 = \text{ores}$	$\dots = 1933$	,, $\frac{1933}{2060} = 0 \cdot 938$
$1 \cdot 286 \times 0 \cdot 334 \times 1000 = \text{hematite}$	$= 429$	,, $\frac{429}{4000} = 0 \cdot 107$
$1 \cdot 286 \times 0 \cdot 208 \times 1000 = \text{silicious ores}$	$= 267$	,, $\frac{267}{3000} = 0 \cdot 089$
$1 \cdot 286 \times 0 \cdot 6 \times 1000 = \text{limestone}$	$= 772$	,, $\frac{772}{1200} = 0 \cdot 643$

Whence the time required by the charge for passing through the furnace = $\frac{211}{6 \cdot 439} = 32 \cdot 78$ hours, and time required for passing through the zone of reduction = $32 \cdot 78 \times 0 \cdot 261 = 8 \cdot 5$ hours; the product is 1286 and $Z = \frac{1000 \times 8 \cdot 5}{1286 - 155} + 1 \frac{1 \cdot 45 - 1}{5} = 8 \cdot 2443$.

We can, therefore, always ascertain in this manner how large the hourly charges have to be, and how much air has to be in-

troduced, if the effect in the zone of reduction has to be increased or decreased, and the normal quantity always to be produced.

Influence of various Methods of working upon Transmission, Consumption of Fuel, and Production, demonstrated by means of a priori Calculation.

By the aid of the method explained in the preceding Chapter, the consumption of fuel may now be calculated *a priori* for any intended mode of working a furnace. To explain this more clearly we will consider the case of a *Rachette* furnace with thick walls, independent zone of preparation, and a capacity of 101 cubic mètres.

We take for our first example that method of working which requires the largest consumption of fuel, but which gives also the purest products, and shall begin by composing a Table of data relating to the heat produced by different consumptions of fuel, taking the coal as containing 80 per cent. of carbon. The ores and flux are those of the charge C used in Wales (see page 208) for foundry iron :

Quantity of coal for 1 Fe	1.15	1.2	1.25	1.3	1.35	1.4	1.45	1.5
Carbon contained in ditto	0.95	0.96	1.00	1.04	1.08	1.12	1.16	1.20
Specific heat of the products of combustion ..	$\left. \begin{array}{l} \text{CO} = 0.532 \quad 0.555 \quad 0.578 \quad 0.601 \quad 0.624 \quad 0.647 \quad 0.670 \quad 0.693 \\ \text{N} = 0.991 \quad 1.035 \quad 1.078 \quad 1.121 \quad 1.164 \quad 1.207 \quad 1.250 \quad 1.293 \end{array} \right\}$							
	1.523	1.590	1.656	1.722	1.788	1.854	1.920	1.986
	Cals.	Cals.	Cals.	Cals.	Cals.	Cals.	Cals.	Cals.
Heat produced	2576	2688	2800	2912	3024	3136	3248	3360
Resulting temperature	1691°.							
Heat absorbed by coke	908	947	987	1026	1066	1105	1145	1185
Available heat	3484	3635	3787	3938	4090	4241	4393	4545
Initial temperature =	2287°.							

This last value is used for calculating the transmission, which is

$$\text{for this furnace } M = \frac{4.8 \times \frac{2287}{2} \times 26}{29228} = 5 \text{ per cent. of the cal-}$$

culated available heat, and the free heat = $\frac{2287 - 1300}{2} = 493^{\circ}$;

The specific heat of the iron at } $1200^{\circ} + 493^{\circ} = 1693^{\circ} = 0.154 = 1 \times 0.154 = 0.154$
 The specific heat of the slags at } $1300^{\circ} + 493^{\circ} = 1793 = 0.359 = 1.304 \times 0.359 = 0.468$

whence the heat absorbed by the products = $493^{\circ} \times (0.154 + 0.468) = 306$ calories.

The heat absorbed by ores, limestone, iron, and slags for the charge C is for No. 4 to No. 15 = 1450 calories; and adding to this the invariable free heat, we get $1450 + 306 = 1756$ calories, and the absorption is as follows:

	Cals.	Cals.	Cals.	Cals.	Cals.	Cals.	Cals.	Cals.
For coals	908	947	987	1026	1066	1105	1145	1185
„ transmission	173	182	188	197	204	212	219	227
„ ores, charges, and free heat	1756	1756	1756	1756	1756	1756	1756	1756
Absorbed in the furnace	2837	2885	2931	2979	3026	3073	3120	3168
Against production	3484	3635	3787	3938	4090	4241	4393	4545
Difference = heat carried off from the furnace	647	750	856	959	1064	1178	1273	1377

The temperatures corresponding with these values are next obtained by dividing the latter by the specific heat of the products of combustion, as found above, plus 0.095 for additional carbonic acid:

	1.15	1.2	1.25	1.3	1.35	1.4	1.45	1.5
	Cals.	Cals.	Cals.	Cals.	Cals.	Cals.	Cals.	Cals.
Heat carried off	647	750	856	959	1064	1178	1273	1377
Temperature	400°	445°	489°	527°	570°	599°	632°	662°

The final temperature of the zone of reduction being 500° , the correct quantity of fuel is thus for this case = 1.3 kil. of coke per kil. of iron. A larger consumption of fuel is not only useless, but as we shall prove hereafter, even disadvantageous for furnaces transmitting great quantities of heat, as the volume of the zones of fusion and gasification, and the time occupied by

the charges in passing through these zones, are thus increased, while the zone of reduction is correspondingly diminished.

The amounts of heat absorbed in the zones of fusion and gasification, which exercise an influence upon the volumes of these zones, are equal to the capacity for heat of the coal, less the weight of the coal multiplied by the specific heat $\times 1000^\circ$: for example, for 1.3 coal this equals $1026 - 367 = 659$, whence we get:

For coal	=	1.3	1.35	1.4	1.45	1.5
		Cals.	Cals.	Cals.	Cals.	Cals.
The absorption	=	659	685	710	736	762
To which has to be added the absorption of No. 9 and No. 11 + 306	=	416	416	416	416	416
		—	—	—	—	—

whence:

Absorption of heat in zones of fusion and gasification	}	1075	1101	1126	1152	1178
The absorption in the zone of reduction is = to the weight of the coal $\times 0.331$ $\times 500^\circ$		215	223	231	240	248
To which has to be again added the por- tions 5, 7, 8, and 10 of furnace C ..	}	572	572	572	572	572
Whence the sum of the zones		1862	1896	1929	1964	1998

But these quantities of heat are proportionate to the volumes of the two zones; and considering therefore the total volume as 1, we shall find it advantageous to also reduce the time required for the passage of the charges through these zones to the same unit, so that the times and volumes may be expressed by the same numbers. These values are now:

V = Z zone of fusion and gasification	0.577	0.581	0.584	0.587	0.590
V = Z zone of reduction	0.423	0.419	0.416	0.413	0.410

It will thus be seen that an increase in the consumption of fuel diminishes the volume of the zone of reduction.

Making now the same calculation for the furnace B, we get:

The consumption ..	= 1.55	1.6
Transmission	= 820	845

$$\begin{array}{ll} \text{Zone of reduction } V = Z = 0.397 & 0.377 \text{ multiplied by} \\ 1 + \frac{1.55 - 1}{5} & 1 + \frac{1.6 - 1}{5} \text{ whence} \\ Z = 0.444 & 0.426; \text{ the time for} \end{array}$$

the passage of the charges through the zone of reduction therefore quickly decreases when the quantity of fuel contained in these charges is increased. Our calculation thus corresponds perfectly with the experience of practical metallurgists, that an excessive quantity of fuel causes an irregular working of the furnace according to the construction and capacity of the latter.

Partial Elimination of the Nitrogen in the Products of Combustion.

The working of the blast-furnace can be still more modified by the elimination of the nitrogen, and the disadvantages produced by the use of mineral fuel can even be almost entirely prevented, and a product obtained that is not much inferior to that obtained when charcoal is used.

These modifications are produced by eliminating more or less nitrogen from the products of combustion, for instance

$$\frac{1}{5}, \frac{1}{4}, \frac{1}{3}, \frac{1}{2}, \frac{2}{3}, \frac{3}{4}, \text{ and } \frac{4}{5}.$$

We shall examine the modifications produced by a successively-increased elimination, supposing that in all cases 1 kil. Fe corresponds to 2 kils. coke, which contain 1.6 kil. of carbon. In order to eliminate now $\frac{1}{5}$ N, we have to introduce $\frac{1}{5}$ of the carbon into the furnace as CO, and have to consume it by a corresponding quantity of air, whence it becomes at first converted into CO², but is afterwards again reduced to CO by means of the solid carbon contained in the furnace, the original volume being thus doubled. This transformation into CO requires $\frac{2}{3}$ of the carbon in the furnace, whilst the remaining $\frac{1}{3}$ are consumed in the usual manner by the blast.

Th...tain, therefore, carbon only as
C

The heat produced by the combustion of the
carbonic oxide is $0.746 \times 2400 \dots = 1790$ calories.

The heat produced by the direct combustion
of the carbon $0.96 \times 2800 \dots = 2688$ „

4478 „

The specific heat of the products of combustion is

$$\left. \begin{array}{l} \text{CO} = 0.925 \\ \text{N} = 1.380 \end{array} \right\} 2.305, \text{ whence } T = \frac{4478}{2.305} = 1940^\circ$$

whence the heat absorbed by the $\frac{2}{3}$ coke in the
charges = $1.6 \times 1940 \times 0.515 \dots = 1598$ „

Available heat = 6076 „

Initial temperature $T' = \frac{6076}{2.305} = 2636^\circ$, and the charges
contain CO $3.733 =$ vols. $2.983 = 39.9$ per cent.
N $5.654 =$ „ $4.499 = 60.1$ „

If more than $\frac{1}{3}$ N is eliminated, no carbon remains in the furnace for combustion in the usual way; but at the same time less air also is introduced for the entire combustion of the CO introduced, and a portion of the latter passes unconsumed through the furnace, and serves both for reducing the temperature of the zone of fusion and for the reduction of the ores.

If $\frac{2}{3}$ of the nitrogen are eliminated, for example, the production of heat is $\frac{2}{3}$ C as CO = $1.245 \times 2400 \dots = 2988$ calories.

The specific heat of the gases = $\left. \begin{array}{l} \text{CO } 0.925 \\ \text{N } 0.574 \end{array} \right\} 1.499,$

therefore $T = \frac{2988}{1.499} = 1993^\circ$, whence $\frac{1}{3}$ of

2 kils. coke contained in the charges, = 0.666
coke, gives $1993 \times 0.666 \times 0.525 \dots = 697$ „

Available heat = 3685 „

Initial temperature = $T' = \frac{3685}{1.499} = 2458^\circ.$

The whole series, calculated in this manner, gives the following results:—

Elimination	$\frac{1}{8}$ Cals.	$\frac{1}{4}$ Cals.	$\frac{1}{2}$ Cals.	$\frac{3}{4}$ Cals.	$\frac{5}{8}$ Cals.	$\frac{3}{2}$ Cals.	$\frac{5}{4}$ Cals.
Heat produced from CO	1790	2240	2985	4478	2988	2239	1790
Heat produced from C	2688	2240	1492	..	..	..	..
Obtained from the coke in the charges	1602	1590	1596	1558	697	376	230
The quantity of coke consumed in furnace	6080	6070	6073	6036	3685	2615	2020
Temperature T =	1940°	2020°	2158°	2506°	1993°	1651°	1499°
Initial temperature T' =	2639°	2737°	2927°	3378°	2458°	1929°	1591°
Specific heat of the gases =	2.305	2.218	2.075	1.787	1.499	1.356	1.270
Volume of CO .. =	2.983	2.983	2.983	2.983	2.983	2.983	2.983
Volume of N .. =	4.499	4.218	3.751	2.812	1.837	1.406	1.125
Vol. per cent. of CO =	39.9	41.4	44.3	51.5	61.9	67.9	72.6
Vol. per cent. of N =	60.1	58.6	55.7	48.5	38.1	32.1	27.4

The initial temperatures increase, therefore, until half of the N is eliminated, but decrease again as the elimination increases, whence we have the choice between the temperature of 2287°, which is that of the ordinary working with cold blast, and those from 1591° to 3378°. This highest initial temperature is exceedingly suitable for foundry iron containing much graphite, like the Scotch pig-iron; and we shall show hereafter that the production can be considerably increased on account of the increased reducing effect and the smaller volume of the richer gases, which permits of the use of the largest capacity and the passing of a correspondingly increased quantity of charges through the zone of reduction.

The initial temperature of 1591°, or even that of 1919°, will permit of the manufacture of a product very similar to spiegeleisen even from ores of inferior quality; for the charges would only contain 0.4 or 0.5 kil. of coke for 1 kil. of iron, whence causes of the impurity of the products would be extremely limited. At the same time the production could be made much larger than it would be with spiegeleisen, on account

of the gases containing only between 32.1 and 27.4 per cent. of N.

The effect on the reducing power of the gases produced by the elimination of nitrogen may be calculated by the formula given in the Appendix to Chapter XX. (p. 203), and is

For an elimination of $\frac{1}{2}$ = $1 + (39.9 - 35) 0.06817 = 1.334$

$\frac{1}{3}$ = $1 + (41.4 - 35) 0.06817 = 1.436$

$\frac{1}{4}$ = $1 + (44.3 - 35) 0.06817 = 1.634$

$\frac{1}{5}$ = $1 + (51.5 - 35) 0.06817 = 2.125$

$\frac{2}{5}$ = $1 + (61.9 - 35) 0.06817 = 2.561$

$\frac{3}{5}$ = $1 + (67.9 - 35) 0.06817 = 3.243$

$\frac{4}{5}$ = $1 + (72.6 - 35) 0.06817 = 3.563$

We shall now first consider the effects of the elimination of the nitrogen on the production of large quantities of foundry iron with a large furnace of a capacity of 325 cubic metres; and besides the elimination of half of the nitrogen the reduction of $\frac{1}{3}$ of the iron in the zone of fusion has to be taken into account.

To begin with, we have to determine the correct consumption of fuel, by calculating successively the consumption of 1.2, 1.25, 1.3, 1.35, and 1.4 of coke in all the different proportions, and we have to choose then that which brings the gases with the minimum temperature of 500° into the separate zone of preparation.

	1.2	1.25	1.3	1.35	1.4
Coke	0.96	1.	1.04	1.08	1.12
Contain carbon					
From which have to be de- ducted for $\frac{1}{3}$ direct reduction	0.071	0.071	0.071	0.071	0.071
Whence remain for combus- tion	C = 0.889	0.929	0.969	1.009	1.049
Half of which has to be in- troduced into the furnace as CO	0.444	0.464	0.484	0.504	0.524
We get thus to consume ..	CO = 1.037	1.084	1.130	1.177	1.225
But the products of combustion contain	CO = 2.074	2.163	2.260	2.354	2.450
And the specific heats of the products of combustion are	N = 1.968	2.052	2.140	2.229	2.317
	CO = 0.514	0.537	0.560	0.583	0.606
	N = 0.479	0.500	0.522	0.544	0.565
Or together	0.993	1.037	1.082	1.127	1.171

Heat produced from CO ..	Cals.	Cals.	Cals.	Cals.	Cals.
Added CO, heated to 400°	2489	2601	2712	2825	2940
produces	103	107	112	116	121
The combustion of which re-					
quires a quantity of air,	247	254	265	276	287
heated to 400°, equal to ..					
	2839	2962	3089	3217	3348
From which has to be deducted					
for heat consumed by direct	170	170	170	170	170
reduction					
	2669	2792	2919	3047	3178
Whence the resulting tem-	2678°	2692°	2698°	2704°	2714°
perature T =					
Heat produced by half the	Cals.	Cals.	Cals.	Cals.	Cals.
coke in the charges (spec.	1060	1110	1157	1204	1254
heat = 0·660)					
Available heat =	3729	3902	4076	4251	4432
Initial temperature	3755°	3763°	3767°	3772°	3785°

The transmission in the furnace is equal to

$$\frac{2 \cdot 9 \frac{3755^\circ}{2} \times 26}{29228} = 4 \cdot 8 \text{ per cent.,}$$

and by substituting each time the initial temperature, we get

$$4 \cdot 8 \quad 4 \cdot 9 \quad 4 \cdot 9 \quad 4 \cdot 9 \quad 4 \cdot 9.$$

The excess of the temperature over that of the point of fusion is successively $\frac{3755 - 1300}{2}$; $\frac{3763 - 1300}{2}$, &c., &c., or

equal to 1227 1231 1233 1236 1242°
 while the specific heat } = 0·184 0·184 0·184 0·184 0·184
 of the iron
 that of the slags .. = 0·453 0·453 0·453 0·453 0·453
 for 1 Fe, therefore .. = 0·184 } = 0·774 multiplied by the
 for slags $1 \cdot 304 \times 0 \cdot 453 = 0 \cdot 590$ } above temperatures.

We get thus the following data relating to the charges equal to those of the furnace C (see page 227)

Coke	1.2	1.25	1.3	1.35	1.4
	Cals.	Cals.	Cals.	Cals.	Cals.
Transmission	179	191	199	208	217
Absorbed free heat	949	952	954	956	961
Heat absorbed by the coke	1060	1110	1157	1204	1254
" " bodies to be smelted	1450	1450	1450	1450	1450
Total absorption	3638	3703	3760	3818	3882
Against available heat	3729	3902	4076	4251	4432
Whence the heat carried off .. =	91	199	316	433	550

We have now to determine the temperatures of the waste gases by dividing these quantities of heat by the specific heat plus 0.095 for additional carbonic acid; we get thus:

$$83^{\circ} \quad 176^{\circ} \quad 269^{\circ} \quad 354^{\circ} \quad 435^{\circ}.$$

Even 1.4 kil. of coke is thus not sufficient, in order to give the waste gases a temperature of 500° , and we must increase the consumption to 1.45.

We then get

$$\text{Specific heat of the products of } \left\{ \begin{array}{l} \text{C O } 0.629 \\ \text{combustion} \end{array} \right\} \left\{ \begin{array}{l} \text{N } 0.587 \\ \text{Cals.} \end{array} \right\} 1.216$$

$$\text{Heat produced from } 1.270 \text{ of C O } \dots 3048$$

$$\text{C O heated to } 400^{\circ} \dots 127$$

$$\text{Air } \dots \dots \dots 297$$

$$\hline 3472$$

$$\text{Less for direct reduction } \dots \dots \dots 170$$

$$3302 = T = \frac{3302}{1.216} = 2715^{\circ}$$

$$\text{Coke brings } \frac{1.45}{2} \times 2715 \times 0.660 = 1299$$

$$\text{Available heat } \dots \dots \dots = 4601. \text{ Initial temperature} = \frac{4601}{1.216} = 3784^{\circ}$$

	Cals.
Whence the transmission .. =	225
Free heat absorbed	961
Heat absorbed by the coke ..	1299
Heat absorbed by the bodies to be smelted }	1450
	<hr/> 3935
Heat produced, or available heat	4601

Whence the heat carried off = 666, which gives to the waste
gases a temperature of $\frac{666}{1 \cdot 216 + 0 \cdot 095} = 508^{\circ}$

The charge for 1000 Fe will thus be — $\frac{1450}{400} = 3 \cdot 625$ cub. mètr. of coke
 $\frac{1369}{2060} = 0 \cdot 665$ „ ores
 $\frac{1000}{1200} = 0 \cdot 833$ „ limestone

5 \cdot 123 „

and we get the time necessary for the passage of the charges
through the furnace = $\frac{325}{5 \cdot 123} = 63 \cdot 43$ hours.

In the zone of fusion are absorbed, or, in other words, the
capacity of heat of the column of fusion between initial tempe-
rature of 3784° and 1000° is :

	Cals.
For the coke $1299 - 204 =$	1095
For absorption in parts Nos. 9 and 11 = $27 + 83 =$	110
Free heat of the products	961
	<hr/>
Heat capacity of the zones of fusion and gasification	2166

The heat capacity of the zone of reduction is :

	Cals.
Coke	119
Absorption in parts Nos. 5, 7, 8, and 10 = $299 + 199 + 26 + 48 =$	572
	<hr/>
	691

These two quantities of heat, or $2166 + 691 = 2857$ calories,
are distributed over the capacity of the furnace of 325 cubic
mètres, and the time of $63 \cdot 43$ hours required for the passage of
the charges through the furnace

This time for, and the volume of, the zones of fusion and gasification are thus	..	=	246.40	cubic mètres	=	48.09	hours,
and those for the zone of reduction	..	}	=	78.60	" "	=	15.34 "
				<hr/>		<hr/>	
				325.00	" "	63.43	"

In order now to reduce the time for the passage of the charges through the zone of reduction to its normal value, we get

$$Z = \frac{1000 \times 15.34}{1000 \times \frac{1000}{3}} \times 1 + (51.5 - 35) \times 0.06817 + \frac{1.45 - 1}{5} = 5.3 \text{ hours.}$$

If the iron produced has to contain now 3 per cent. of carbon, the charges have to be arranged in such a manner that the value Z' is equal to 16. We find that by means of the formula

$$\frac{V \times 1000 \times m}{x^3 G F}.$$

We have

$G = 5.123 = \log. 0.70952$	$V = 78.6 = \log. 1.89546$
$F = 666$	$1000 \times m = 2215 = \log. 3.34537$
2.82347	<hr/>
3.53299	$\log. 5.24083$
$x^2 = .50376$	$\log. 4.03675$
<hr/>	<hr/>
$\log. 4.03675$	$\log. 1.20408 = 15.999$

we get after some manipulations $x = 1.783$, and the hourly charge is thus :

$1.783 \times 1.45 \times 1000 = 2590$ coke	$\frac{2590}{400} = 6.474$ cubic mètres.
$1.783 \times 1.369 \times 1000 = 2445$ ores	$\frac{2445}{2060} = 1.187$ "
$1.783 \times 1 \times 1000 = 1783$ limestone	$\frac{1783}{1200} = 1.488$ "
	<hr/>
	9.149 "

whence the time necessary for the passage of the charges through the furnace = $\frac{325}{9.149} = 35.52$ hours, and for their passage through the zone of reduction $\frac{78.6 \times 35.52}{325} = 8.59$, and, therefore,

$$Z = \frac{1000 \times 8.591}{1783 - 595} \times 1 + (51.5 - 35) \times 0.06819 + \frac{1.45 - 1}{5} = 15.99.$$

Now, the difficulty is to consume in the furnace really 2590 kilogrammes per hour, which would give, with the ordinary mode of working, per second, $\frac{2590}{3600} = 0.719$ coke = 0.575 C = 1.3416 C O + 2.5878 N = $\frac{1.3416}{1.2515} + \frac{2.5878}{1.2566} = 3.131$ cubic mètres of gas, but by eliminating half the quantity of nitrogen, the quantity of the gas is reduced to only = 2.101 cubic mètres. This is a considerable advantage, but it is scarcely possible with the ordinary construction of the furnaces to blow through such a quantity.

We shall examine, therefore, what the furnace chosen for our investigations can offer in this respect. The height of this furnace from the tuyere holes to the top of the charges is 12 mètres, the diameter between the tuyere holes is 0.9 mètre, that above the tuyere holes 9 mètres, and the diameter of the boshes is 4.8 mètres. The narrow walls of the furnace are 7.2 mètres long in the direction of the tuyere holes, and 8.7 mètres at the boshes from where they rise perpendicularly.

Dividing now the vertical height into 12 equal parts, we find for the average section and capacity of these parts:

Square and cubic mètres: 8.325, 11.908, 15.834, 19.545, 24.259, 28.778, 33.442, 38.305, 41.283, 41.325, 40.455, and 39.585.

The
have

are exceedingly small, we
zone of fusion. The

1.072 cubic mètre of CO per second, immediately produces on entering the furnace 1.072 cubic mètre of CO². Now, 1 cubic mètre of CO² requires for its reduction to CO, 12 square mètres of surface of contact, and 1 cubic mètre of coke offers a surface of contact of 104.72 square mètres, whence only $\frac{1.072 \times 12}{104.72} =$

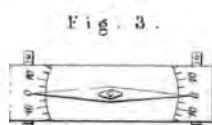
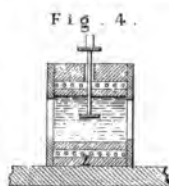
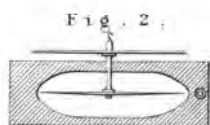
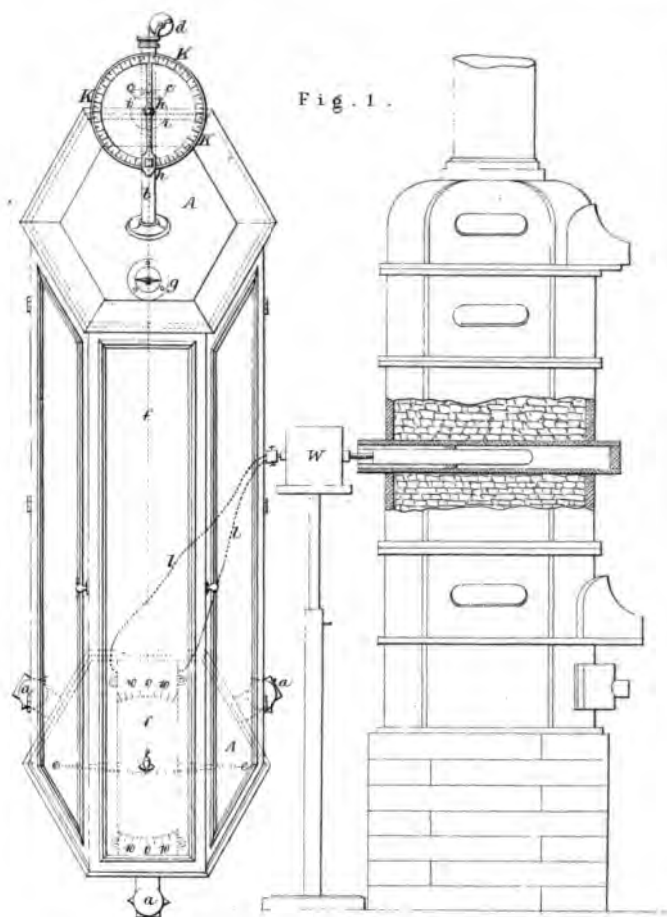
0.123 cubic mètre are required as space for the reduction, which corresponds to less than $\frac{1}{80}$ of the height of the first part. The limit between the zone of fusion and zone of reduction is thus 9.05 mètres above the tuyere holes, whilst the zone of reduction occupies a height of 2.95 mètres.

The increase of the temperature, which is from 500° to 1000° in the zone of reduction, and from 1000° to 3784° in the zone of fusion, can now be easily calculated for the different parts by making the decrease of temperature proportionate to the area of the parts, for the temperature of 1000° is almost exactly between two of the parts. In order to make these temperatures now applicable to the calculation of the resistance of the column of fusion, we have only to take the mean of two, as we have done for the sections.

The resistances are given in the following Table, in which the size of the pieces of coke and all the other factors are taken equal those in the Tables of Chapter XXXVIII.

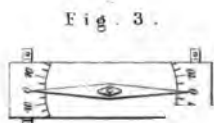
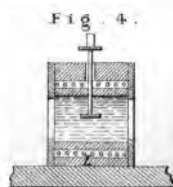
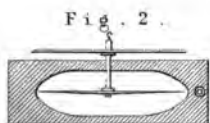
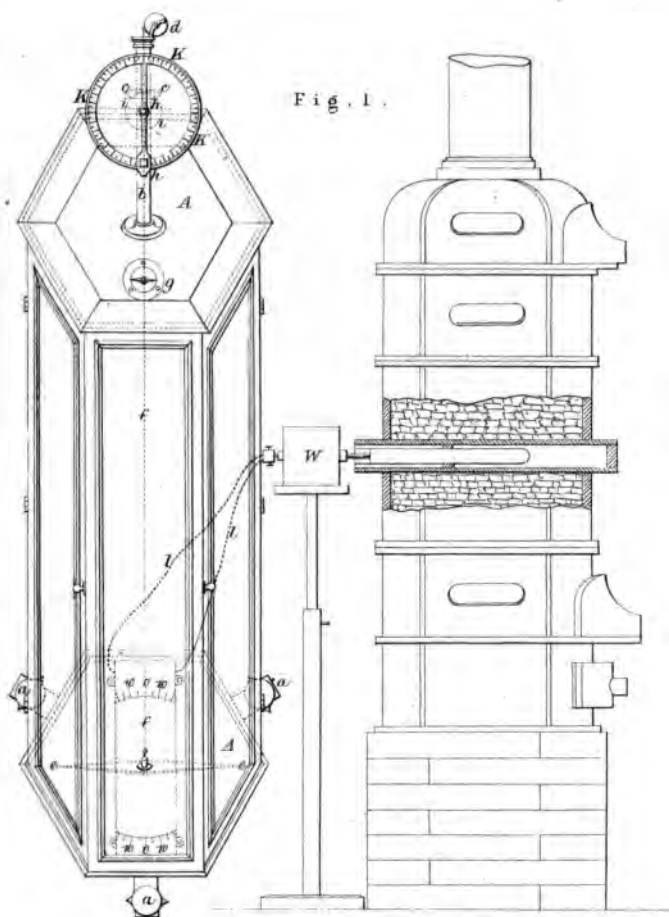
Parts.	Temperature of the Gases. °	Volume of the Gases at 0°.	Volume of the Gases at $T_0 = V_0$.	Average Section, S.	Free Section, S ₀ .	Velocity $v = \frac{V_0}{S_0}$ mètres.	$\frac{v^2}{2g} = p$ mètres.	n pièces.	KCF $S_0 \frac{v^2}{4g}$ p.	n p.	Total
1	3528	2-101	cub. mètr. 29-257	sq. mètr. 8-235	sq. mètr. 1-767	mètres. 18-563	13-990	20	40-965	279-80	320-765
2	3028	..	26-008	11-908	2-555	10-179	5-284	..	15-474	105-78	121-254
3	2578	..	21-952	15-834	3-398	6-460	2-128	..	9-726	42-56	49-286
4	2187	..	18-941	19-945	4-280	4-428	0-998	..	2-924	19-98	22-904
5	1854	..	16-377	24-259	5-206	3-146	0-505	..	1-477	10-10	11-577
6	1577	..	14-244	28-788	6-178	2-305	0-271	..	0-793	5-42	6-213
7	1352	..	12-512	33-442	7-127	1-755	0-157	..	0-464	3-14	3-604
8	1178	..	11-172	38-305	8-220	1-359	0-094	..	0-276	1-88	2-156
9	1051	..	10-194	41-283	8-859	1-151	0-067	..	0-198	1-34	1-538
10	941	..	9-347	41-325	8-868	1-054	0-056	..	0-166	1-12	1-286
11	746	..	7-845	49-455	8-682	0-913	0-041	..	0-123	0-82	0-943
12	581	..	6-575	39-525	8-482	0-775	0-030	..	0-090	0-60	0-690
											542-216

The pressure necessary for the blast is, therefore, still very small, not yet $\frac{1}{34}$ th of that required by the small circular furnace in Chapter XXVIII., and this construction of furnace is thus well suited to produce such a considerable quantity as 1783 kils. of Fe per hour, without any considerable pressure of the blast.



Parts.	Tempera- ture of the Gases.	Volume of the Gases at 60°.	Volume of the Gases at $T_0 = V_0$.	Average Section, S.	Free Section, So.	Velocity $v = \frac{V_0}{S_0}$	$\frac{v^2}{2g} = p$.	$\frac{v}{\text{mètres.}}$	$\frac{KCF}{S} \cdot \frac{p}{480}$.	n p.	Total
	°	cu. mè.	cu. mè.	sq. mè.	sq. mè.	mètres.	mètres.				
1	3528	2·101	29·267	8·235	1·767	16·563	13·990	20	40·965	279·80	320·765
2	3028	..	26·008	11·908	2·555	10·179	5·284	..	15·474	105·78	121·254
3	2578	..	21·952	15·834	3·398	6·460	2·128	..	6·726	42·56	49·286
4	2187	..	18·941	19·945	4·280	4·428	0·998	..	2·924	19·98	22·904
5	1854	..	16·377	24·259	5·206	3·146	0·505	..	1·477	10·10	11·577
6	1577	..	14·244	28·788	6·178	2·305	0·271	..	0·793	5·42	6·213
7	1352	..	12·512	33·442	7·127	1·755	0·157	..	0·464	3·14	3·604
8	1178	..	11·172	38·305	8·220	1·359	0·094	..	0·276	1·88	2·156
9	1051	..	10·194	41·283	8·859	1·151	0·067	..	0·198	1·34	1·538
10	941	..	9·347	41·325	8·868	1·054	0·056	..	0·166	1·12	1·286
11	746	..	7·845	49·455	8·682	0·913	0·041	..	0·123	0·82	0·943
12	581	..	6·575	39·525	8·482	0·775	0·030	..	0·090	0·60	0·690
											542·216

The pressure necessary for the blast is, therefore, still very small, not yet $\frac{1}{10}$ th of that required by the small circular furnace in Chapter XXVIII., and this construction of furnace is thus well suited to produce such a considerable quantity as 1783 kils. of Fe per hour, without any considerable pressure of the blast.



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Fig. 5.

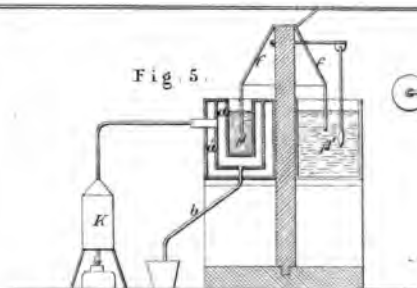


Fig. 6.

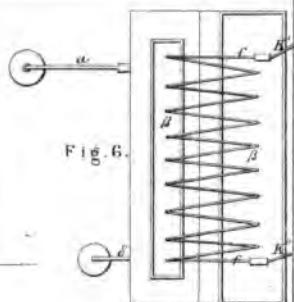


Fig. 8.

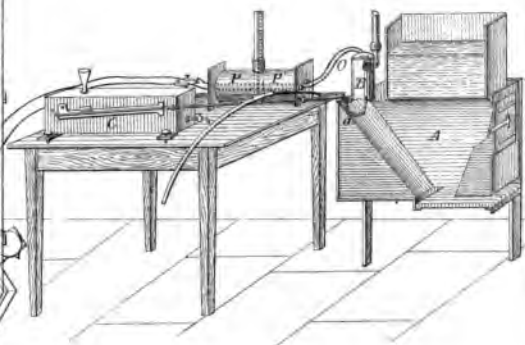
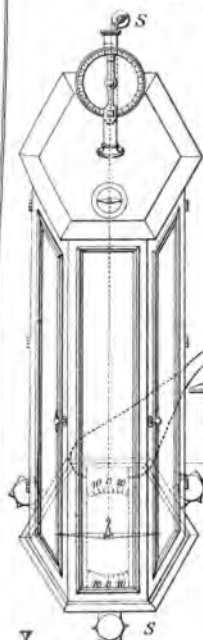


Fig. 7.

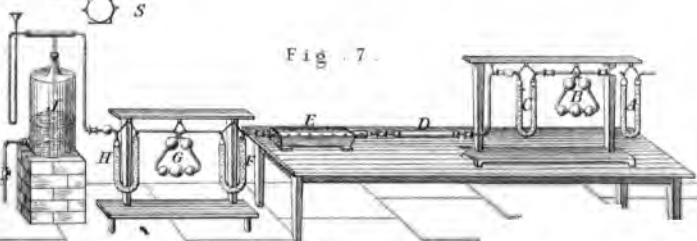


Fig 9.

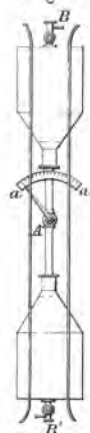


Fig 10.



Fig 11.

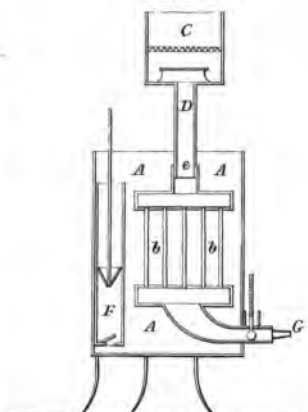


Fig. 13.



Fig. 12.

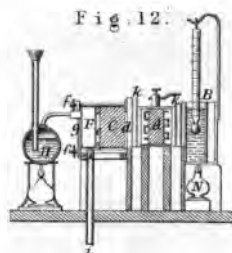
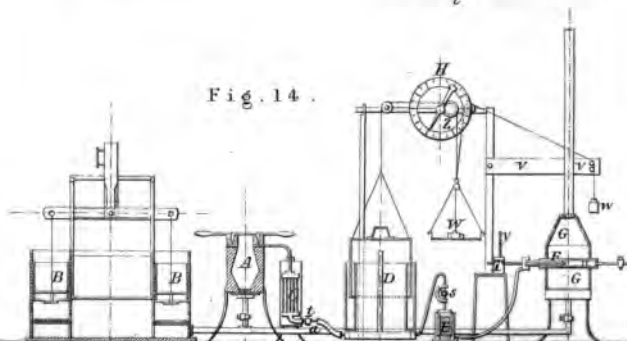


Fig. 14.



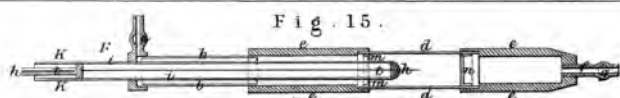


Fig. 16.

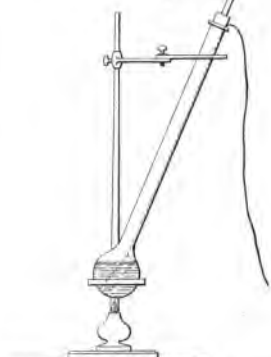


Fig. 17.

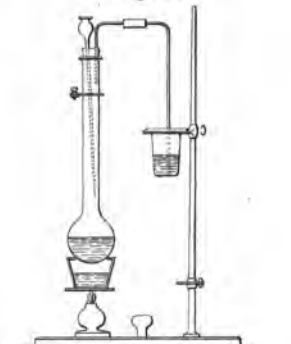


Fig. 18.

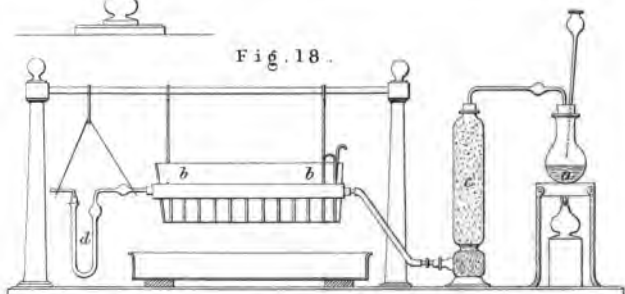
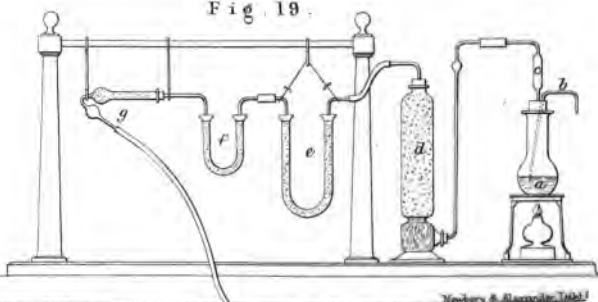


Fig. 19.



Wentley & Mansel, 1861

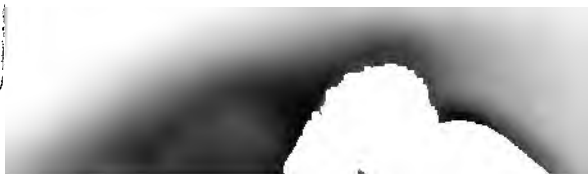


Fig. 21.

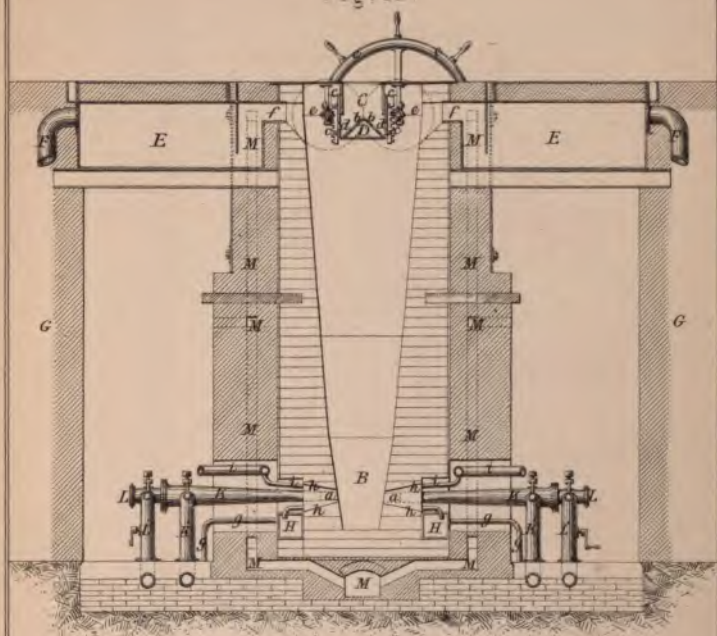
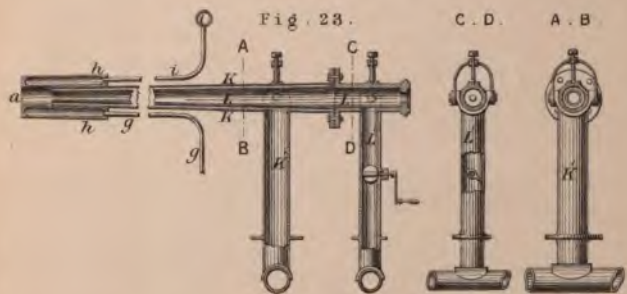


Fig. 23.



Scale for Fig. 23.

Scale for Fig. 21.

Woolley & Macdonald, Telford & Co., Glasgow & London.

E. & F. N. Spon, 45 Charing Cross London.

Fig. 21.

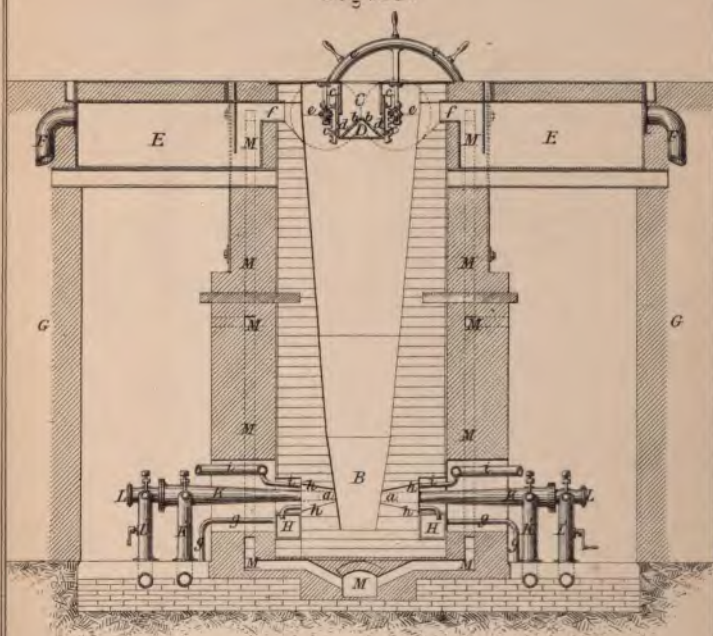
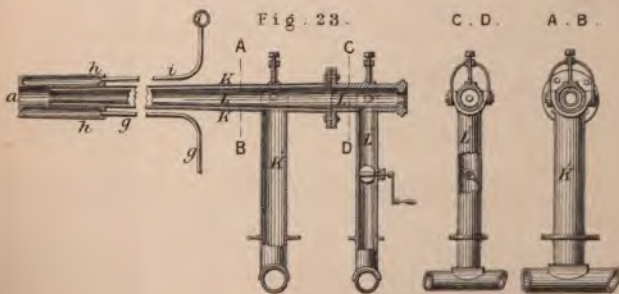


Fig. 23.



Scale for Fig. 23. 0 1 2 3 4 Meters

Scale for Fig. 21. 0 1 2 3 4 5 6 7 8 9 10 Meters

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Fig. 26.



Fig. 27.

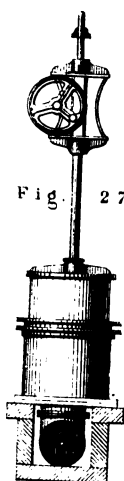
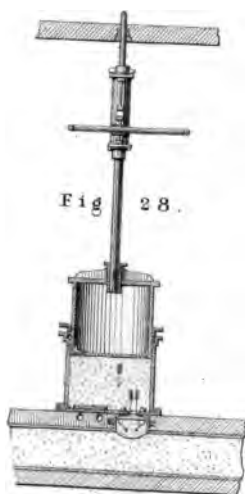


Fig. 28.



Scale for Figs 24 & 25.

